Income inequality and mitigation burdens: An examination of climate mitigation fair shares for South African households.

by

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ABSTRACT

Equity is an essential issue for climate change mitigation, especially when considering the needs of a large global population in the developing world. The principle of common but differentiated responsibilities and respective capabilities (CBDR/RC) aims to ensure equitable sharing of the climate action burden for signatories given nations' differing historical and current circumstances, but equitable burden-sharing might also be achieved if implemented through policies at a national level. South Africa is highly unequal and effectively has two parallel economies, a developed one that primarily serves the wealthy, and a developing one in which the majority of the population lives (Mbeki, 2003). As such, it internally reflects the global tension between necessary climate action and essential developmental goals. This study evaluates fair intra-national household mitigation shares in South Africa considering the principle of CBDR/RC, and the policy implications of achieving equitable mitigation action.

Emulating a study by Arndt et al (2013), an energy-integrated supply-use table (SUT) model is used to examine embodied emissions for aggregate products and industries in the South African economy for three time periods (2005, 2010 and 2015). Household emissions from direct and indirect fossil fuel consumption are assessed by integrating household consumption survey data through multiplier analysis. Household emissions reflect the same "two economies" disparity as income when measured by means of both Gini and Palma indices. A small decline in inequality is observed over the study period, but overall emissions and income inequality in 2015 remain high.

Grouping households by mean per capita income and expenditure, household responsibility and capability are assessed as shares of total household emissions and income, respectively. Holz *et al.* (2017) propose a minimal developmental threshold of $7,500 PPP below which individuals should not bear any mitigation burden, and application of this threshold provides household threshold capability and a combined mitigation and responsibility household equity estimate. Simple equity measures indicate that the top household decile's fair share of all mitigation action is between 44% and 54%, whilst the share of the bottom four deciles is between 5% and 11%. When considering the development threshold, some three-quarters of households would have no burden at all. Finally, the combined equity estimate highlights that the top decile is overwhelmingly responsible for the burden of mitigation action, with the top 2% of households by income carrying 48.1% of the mitigation burden.

An assessment of the correspondence between in South Africa's international and national policy concludes that intra-national mitigation equity is necessary to achieve developmental and mitigation goals. National mitigation implementation should therefore secure revenue for mitigation through progressive means. Direct revenue recycling may enhance the security net for low-income households and provide a safety net as the country experiences unavoidable employment shifts during the transition to a low-carbon economy.

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LIST OF ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
CB	Consumption-based
CBDR/RC	Common but differentiated rights and respective capabilities
CERC	Climate Equity Reference Calculator
CIM	Carbon Intensity Measure
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COICOP	Classification of Individual Consumption by Purpose
CPC	Central Product Classification
CPI	Consumer Price Index
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry and Fisheries
DMRE	Department of Mineral Resources and Energy
DoE	Department of Energy
GDP	gross domestic product
GHG	greenhouse gas
IES	Income and Expenditure Survey
IO	Input-output
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
LCS	Living Conditions Survey
MPE	Marginal propensity to emit
Mt	Megatonnes (million metric tonnes, or gigagrams)
NCCRWP	National Climate Change Response White Paper
NDC	Nationally Determined Contribution [to the Paris Agreement]
NDP	National Development Plan
NPC	National Planning Commission
Pc_exp	Households classified by per capita expenditure
Pc_inc	Households classified by per capita income
PPP	Purchasing power parity
RSA	Republic of South Africa
StatsSA	Department of Statistics South Africa
SU	Supply-use
SUT	Supply-use tables
UBI	Universal Basic Income
UBIG	Universal Basic Income Grant
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1: INTRODUCTION

1.1 Background

Anthropogenic climate change caused by land-use change and the burning of fossil fuels may be the biggest crisis ever to face humanity. With considerable evidence pointing to the potential for a near-term tipping point (Barnosky et al., 2012) beyond which the earth's capacity to support humanity will be greatly reduced (Steffen et al., 2018; Lenton et al., 2019), urgent universal mitigation action is imperative. The 2015 Paris Agreement's long-term mitigation goal mitigation requires balancing emissions and sinks, in the context of equity, poverty eradication and sustainable development. With 186 countries making nationally determined contributions (NDCs) to the Agreement, it represents unprecedented global cooperation.

It is also imperative to address key human development goals over the same period, in line with the UN's Sustainable Development Goals (Nicolai et al., 2015). Aligning these two objectives requires achieving a "safe and just space for humanity" (Raworth, 2012) that both enables humanity's basic developmental needs and avoids exceeding the planetary boundaries within which continued life is possible (Rockström et al., 2009).

The perceived trade-offs between development and climate mitigation give rise to one of global mitigation action's key challenges; the assessment of "fair shares", or determining which parties are responsible for what portion of the action. The United Nations Framework Convention on Climate Change (UNFCCC, 1992 Article 3.1), and the convention's Paris Agreement (UNFCCC, 2015) both refer to "common but differentiated responsibilities and respective capabilities" (CBDR/RC) in addressing climate change. This principle aims to ensure that mitigation action does not limit nations' ability to achieve essential developmental goals. The principle implies that a larger mitigation burden should fall to those nations with greater responsibility and capacity to undertake such action, although there is limited common ground for interpreting this principle between nations (Holz, Kartha & Athanasiou, 2017). Paris Agreement signatories have committed to rapidly peak greenhouse gas (GHG) emissions, reaching a balance between emissions and removals by the second half of the century. South Africa's NDC commits to achieving the Paris Agreement goals (RSA, 2016), whilst still advocating that the developing nation's mitigation burden should be considerably lower than that of developed nations.

Individual nation states (Parties to the UNFCCC) are the basic entity for negotiations and most academic exploration, with limited analysis examining personal obligations at an intra-national level. The current Paris Agreement framework provides for Parties to determine their own national mitigation commitment. Such action typically considers only policy actions and their potential impacts on

mitigation or adaptation, without considering whether the impact on citizens reflects the fair share principles emphasised in the international arena.

Some academic burden-sharing approaches that consider sub- or intra-national emissions inequality propose exemptions to ensure some level of basic human welfare (Baer et al., 2008; Kemp-Benedict et al., 2017). Rao (2014) points out that implementing such exemptions within international agreements is challenging: broad exemptions can give rise to wealthy free riders in developing states, and otherwise (or even concurrently) create unjustified mitigation burdens for the poor. Individual equity ideally should therefore not be directed through international agreements, but rather pursued through nations' own internal policies, considering specific national circumstances.

Understanding citizen's respective responsibilities and capabilities for climate action might be considered an essential point of departure for designing climate mitigation and adaptation policy that fairly distributes burdens and benefits of the transition process. For South Africa, this should be an essential consideration. With structural inequality that makes the nation the world's most unequal society in terms of both income (World Bank, 2019) and wealth (Orthofer, 2017), South Africa effectively has separate economies for the rich and the poor (Mbeki, 2003). If citizens' responsibility for and respective capabilities to address climate change differ, a reasonable fair share allocation would rule out equal burdens for mitigation action.

This thesis adapts an international climate fair shares approach to intra-national equity and addresses the challenge of enabling development whilst ensuring climate mitigation within South Africa. Addressing inequality and poverty are critical elements for national developmental policy (DEA, 2012; NPC, 2012), and the challenge of achieving mitigation requirements within this political milieu is contingent on ensuring the achievement developmental goals.

It is thus necessary to understand the relationship between income, expenditure, and emissions within the context of the economy, and to assess levels of inequality for each. The country exhibits tendencies that imply higher carbon emission footprints for high-income households, such as larger houses (Schaffrin & Reibling, 2015), smaller household sizes (Underwood & Zahran, 2015), and higher incidences of personal transport, but an accurate accounting has not been undertaken to date.

1.2 Research question and objectives

In light of the UNFCCC principle of climate equity articulated as CBDR/RC and South Africa's "two economies" structural inequality, this thesis asks "Is South Africa's income inequality reflected in household GHG emissions, and what are the implications for fairly allocating the country's mitigation burden?"

1.2.1 Aim

The aim of this thesis is therefore to develop measures of household capability and responsibility in relation to economic inequality, and to explore the policy implications of attributing fair household mitigation shares at an intra-national level.

1.2.2 Objectives

To achieve this aim, the thesis addresses the following objectives:

1. Examine the relationship between household GHG emissions and household income and expenditure by means of household carbon intensity;
2. Examine the correspondence and variance in economic inequality between households and emissions inequality;[1]
3. Assess whether these relationships have changed over time;
4. Assess fair shares of the mitigation burden for households in different economic groupings, drawing on the analyses in Objectives 1 to 3; and
5. Discuss the policy implications and options of such a fair share attribution.

It might be expected *ex ante* that households with greater expenditure would be responsible for higher emissions (corresponding to household responsibility as discussed later). This thesis reaches beyond such a simple measure of mitigation obligation, by first examining whether the levels of income inequality are reflected by emissions inequality (since the structure of expenditure varies within different income groups), and then considering the capability of households to address climate change by consideration of income. This allows for a more nuanced assessment of household obligation in light of the principle of CBDR/RC.

1.3 Thesis structure

Chapter 1 introduces the thesis, outlining the research question, aims and objectives.

Chapter 2 reviews literature illustrating the discussion on international and intra-national climate equity. This chapter also provides a background on income and wealth inequality in South Africa, and a review of methodologies for assessing GHG emissions at a household level.

[1] Objective 2 is to some extent dependent on the outcome of objective 1. The level of emissions inequality determined in Objective 1 will affect the analysis in level 2. Should there be very differing levels of inequality between emissions and income (or no inequality in emissions between household groups), it may be a failure of the model, requiring deeper analysis of the SU approach. More broadly, a comparison of the levels of inequality could be driven by differences in expenditure between household income groups, which can be unpacked through examination of the SU model.

Chapter 3 details the datasets and the selected methodology used for analysis of household level emissions in this thesis. Using an approach outlined by Arndt *et al.* (2015), full supply-use tables and multiplier analysis are used to trace the embodied carbon impact of intermediate products to final consumption. Household consumption and income data from the national statistics agency combined with energy data from the Department of Mineral Resources and Energy (DMRE)[2] and national electricity supplier Eskom enable assessment of household emissions.

Chapter 4 presents the results of the modelling work. In addition to examining the linkage between household income and emissions, it also explores whether an alternative measure to income (household expenditure) provides a significantly different perspective. The model also explores whether there has been significant change in inequality measures over the period 2005 to 2015. Finally, the chapter illustrates fair shares for households using measures of responsibility and capability.

Building on the model's results, Chapter 5 considers the implications for South African climate change and developmental policy. Specifically, this chapter explores whether current national and international policy align on the equity implications of emissions and inequality, and briefly explores options for facilitating intra-national mitigation in line with CBDR/RC.

The final chapter provides conclusions around the overall research aim and secondary objectives, summarises the overall findings, and provides suggestions for potential additional analysis.

[2] National government departments were restructured in June 2019. The energy portfolio currently under DMRE was previous the Department of Energy (DoE). Similarly, the UNFCCC focal point is the Environment portfolio, currently within the Department of Environment, Forestry and Fisheries (DEFF), and previously the Department of Environmental Affairs (DEA). This thesis uses the current designations throughout, except in references published under a previous designation.

CHAPTER 2: LITERATURE REVIEW

Anthropogenic emissions are the leading driver of climate change, primarily through the burning of fossil fuels and land use change. Urgent climate change mitigation action is required to achieve the global goal of limiting climate change to well below 2°C, with efforts to limit it to 1.5°C above pre-industrial levels (IPCC, 2018a). The current trajectory of increasing emissions means that the chances of limiting climate change to this level are increasingly slim (Mauritsen & Pincus, 2017; Millar et al., 2017; Raftery et al., 2017), whilst recent evidence indicates that even 2°C may exceed a reasonable limit or "planetary boundary" to safe development (Hansen et al., 2013; Steffen et al., 2015; Schleussner et al., 2016).

For many developing countries, the need to meet basic human needs through economic development is a countervailing priority. Budolfson (2017) proposes that if mitigation costs are borne by the rich, the effects of climate change are disproportionately borne by the poor, and low discount rates are used in planning, then inequality aversion may increase the motivation to mitigate on the basis of impacts to future generations. However, in general the mitigation-development dilemma is the driver of policy inadequacy and contradiction both within international negotiations and national developmental and mitigation policy.

The enormous economic and emissions inequality between nations caused a long-term impasse in setting substantial binding targets for mitigation (Heil & Wodon, 1997), and challenged negotiations around mitigation effort-sharing (Bhatti, Lindskow & Pedersen, 2010; Tørstad & Sælen, 2018). The key principle of equity articulated in the United Nations Framework Convention on Climate Change (UNFCCC, 1992) has lent itself to multiple analyses of fair shares, and the development of effort-sharing frameworks (Höhne & Moltmann, 2009; Winkler, Letete & Marquard, 2013; Höhne, den Elzen & Escalante, 2014; Pan et al., 2017). The current bottom-up NDCs under the Paris Agreement are inadequate for limiting climate change to well below 2°C (Rogelj et al., 2016), and national justifications for these commitments are largely unsatisfactory (Mbeva & Pauw, 2016; Winkler et al., 2018). Nations' fairness rationales align strongly with whether a country is on Annex I of the UNFCCC (Tørstad & Sælen, 2018), and commitments demonstrably align with the least stringent effort sharing approach in each case (du Pont & Meinshausen, 2018).

Each nation has committed to mitigation in its NDC under Article 4.2 of the Paris Agreement (UNFCCC, 2015), regardless of the equity approach chosen. This thesis is most interested in the national and intra-national implementation of this commitment. The rationale for considering income inequality and emissions at a sub-national or household level is twofold. Firstly, there is a critical question regarding the impact of developmental goals on national mitigation strategy: if reducing inequality impacts total emissions, then aligning developmental and mitigation strategies is essential.

This first element is broadly – and inconclusively –examined in the literature, and this thesis aims to provide more evidence for an appropriate apportionment of the national emissions profile at a household level. Secondly, there is an ethical question of who should bear the cost of mitigation *within* the country, similar to the international equity debate focused on comparisons *between* countries. If there is indeed a significant difference in household responsibility and capability, then a differentiated intra-national approach to mitigation may be warranted.

The interface of mitigation equity considerations with income and wealth inequality at an intra-national (household or individual) level is therefore extremely important when considering the ethical implications of policy goals.

2.1 Mitigation and equity

2.1.1 International mitigation and equity

The UNFCCC principle of CBDR/RC highlights that mitigation obligations should consider equity variables, notably responsibility (a nation's historical contribution to the total global anthropogenic greenhouse gas (GHG) emissions); and capability (the economic, technical and infrastructural ability to curtail or prevent emissions) (UNFCCC, 1992 Article 3.1).

This differentiation is critical. The Paris Agreement commits all countries to mitigation action, but considers that: "*The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration."* (UNFCCC, 2015; Article 3.2).

South Africa's historical emissions are approximately one percent of the global total, placing it in the top 20 nations by responsibility (Kemp-Benedict et al., 2017). However, the nation's low aggregate developmental level and high poverty rates imply a low respective capability. This dichotomy of obligation with limited capability has been a key driver of South Africa's negotiating stance, stressing that developing country mitigation action should be contingent on adequate finance provision from developed nations (RSA, 2016). This stance provides a useful lens through which to contemplate the concept of South Africa's sub- or intranational equity in mitigation action.

Another useful lens is the consumption-based (CB) approach, which attributes emissions responsibility at the point of a product's consumption (Davis & Caldeira, 2010; Peters, Davis & Andrew, 2012; Afionis et al., 2017). This approach has gained credence in mitigation literature (though not in international negotiations) principally because developed nations' recent decarbonisation trends are

somewhat offset by increased imports of finished products – effectively outsourcing emissions (Peters, Davis & Andrew, 2012; Wiedmann et al., 2015). The CB approach is pertinent to fair shares at the intra-national level. Assigning responsibility (and thus cost) to a product's consumer incentivises reduced consumption, facilitates mitigation action at the source of emissions (Afionis et al., 2017), and is already being used in a number of areas (Kokoni & Skea, 2014).

2.1.2 Intranational mitigation and equity

Most burden-sharing principles treat states as homogenous entities, although more nuanced approaches exist which consider sub-national income and emissions heterogeneity (Baer et al., 2008; Kemp-Benedict et al., 2017). Such approaches argue for exemptions that ensure basic human welfare, articulated as a developmental threshold (Baer et al., 2008), or a right to subsistence (Shue, 1993). For instance, the Climate Equity Reference Framework (Holz, Kartha & Athanasiou, 2017) details a $7,500 "developmental income threshold" below which poverty legitimately dictates that development should be the exclusive priority. This measure has been used in several civil society assessments of equity within the international negotiations (CSO Equity Review, 2017).

International exemptions on the basis of such thresholds run the risk of creating "free-riders" of rich citizens who exceed the threshold, whilst unfairly burdening the poor in non-exempt countries (Rao, 2014). Further, the ethical implication that mitigation burdens be borne only by those citizens above this threshold may not be implemented in national-level policy. Typically, mitigation policy is driven by strongly embedded political economies, hampering progressivity of such action.

Assuming a nation opts to undertake an equitable approach to mitigation, multiple approaches are available (broad-based mitigation combined with poverty reduction measures, progressive mitigation targeting, specific exemptions) which could have potential synergistic or perverse impacts depending on the national policy mix. In general, shielding the poor from mitigation obligations is a non-trivial matter.

There is evidence to show that mitigation action has potential upsides including co-benefits of low-carbon development and reduced energy consumption , as well as the strategic and negotiating advantages of strong signalling (Bernard et al., 2015). Many potential mitigation activities would benefit the poor, but these are not necessarily pursued (Casillas & Kammen, 2012).

2.2 Income, inequality and GHG emissions

The impacts of income and income inequality on emissions are moderately well-studied at the global scale. Whilst income and income inequality are related, relationships with environmental impacts differ, and it is worth considering each independently before discussing their interaction.

2.2.1 Income

Ehrlich and Holdren (1971), contemporaneously with Barry Commoner (1971), postulated that the key drivers of environmental impacts were a combination of population, affluence and technology. Termed the IPAT theory, it was central to the development of early the Intergovernmental Panel on Climate Change (IPCC) development scenarios (Nakicenovic et al., 2000). IPAT theory in turn gave rise to the Kaya identity (Nakicenovic, 1997), which expresses overall global greenhouse gas emissions as:

$$Total\ emissions\ =\ population\ *\frac{affluence}{population}*\frac{energy\ used}{affluence}*\frac{emissions}{energy}$$

The Kaya identity provides a useful framework for measuring global emissions by linking them to measures already tracked in national accounts (Peters et al., 2017).

Assumptions of equal elasticity notwithstanding, economists typically reify income and wealth measures as those most amenable to direct intervention from a policy perspective (Carson, 2009). Certainly, population growth is contentious and challenging to address, as evidenced by the experience of China. The rise of the environmental Kuznets curve (EKC) theory reflects this reification of income measures. First observed for broad aggregate pollution impacts, the EKC posits that environmental impact follows an inverted U-shaped curve when plotted against gross domestic product (GDP) or income (Selden & Song, 1994; Grossman & Krueger, 1995). Early descriptions of the EKC postulated that increasing per capita income would reduce overall pollution levels, essentially decoupling GDP and pollution impacts. This prompted several decades of technocratic economic approaches to environmental management that dominated much of the economic literature, advocating for increased economic growth to enable a such a decoupling.

Recent literature suggests that the EKC does not apply universally, does not generally hold for carbon dioxide emissions (Stern, 2004; Aslanidis & Iranzo, 2009), and decoupling is insufficient to achieve global goals (Vadén et al., 2020). To conclude that increased income benefits the environment is challenging in light of difficulties in interpreting causation (Kolstad, 2006). It has become apparent that the posited causal relationship between improved environmental quality and income alone is highly unlikely (Rosa & Dietz, 2012), and is often better explained by concurrent good governance, effective regulations and improved technological inputs (Carson, 2009).

Evidence for the EKC at an intranational (household or individual) level is weak, especially for carbon emissions. The strongest correlate for high carbon emissions is high income or expenditure (Duarte, Mainar & Sánchez-Chóliz, 2012; Golley & Meng, 2012; Perobelli, Faria & Vale, 2015; Schaffrin & Reibling, 2015; López et al., 2017) despite reduced household carbon intensity from increased financial services expenditure (Arndt et al., 2013). Household carbon emissions are typically driven by total expenditure on wealth correlates such as smaller households (Underwood & Zahran, 2015), higher

energy consumption and larger houses (Schaffrin & Reibling, 2015), and higher rates of car ownership and larger travel distances (Cox et al., 2012; Brand et al., 2013). It thus appears that whilst focussing on resource efficiency and low carbon development trajectories is of value, it is unlikely to be sufficient on its own to address the key problems (Ala-Mantila, Heinonen & Junnila, 2014).

2.2.2 Inequality and emissions

The national marginal propensity to emit (MPE) demonstrably varies with income, but emissions are also impacted by factors such as inequality (Grunewald et al., 2017). Ravallion, Heil and Jalan (2000) postulate that the MPE decreases linearly with increasing income, which is supported by some other studies (Holtz-Eakin & Selden, 1995). If universally true, increasing inequality would decrease net emissions per unit national income, as low-emitting high-income individuals capture a larger proportion of income.

Similarly, if the EKC curve is valid, then high inequality would reduce emissions – the higher proportion of low-emitting rich and poor corresponds to a reduced high-emitting middle class (Heerink, Mulatu & Bulte, 2001). This is particularly true where low income households experience energy poverty since they have particularly low emissions rates.

A third case, in which MPE directly correlates to increased income, has been demonstrated for China as a whole (Golley & Meng, 2012) and for rural China in particular (Wiedenhofer et al., 2017). Decreasing inequality would reduce emissions in such a case. Several studies conclude that a reduction in inequality in China would indeed reduce per capita emissions in some regions (Hao, Chen & Zhang, 2016), and on balance reduce per capita emissions for the country as a whole. (Zhang & Zhao, 2014)

Berthe and Elie (2015) provide a good review of literature regarding the emissions impact of reducing inequality. Considering 14 empirical research papers examining the impacts of income inequality on a broad range of environmental issues, they conclude that the results depend on the researcher's hypotheses regarding the individual environmental pressure and income, the social norms, interest groups and political demands relating to the environmental impacts, and the manner in with policy is derived from this social milieu.

The literature on income inequality reduction is thus unclear on whether it helps or hinders mitigation. Rather, it is important to assess the role of income and carbon inequality for a given nation to determine likely outcomes. Given the ethical imperatives for both poverty reduction and mitigation, the importance of assessing the impacts of policies designed to achieve either outcome is critical. This is particularly the case for nations with relatively high incomes but high levels of poverty, such as South Africa.

2.2.2.1 International inequality

Inter-country analysis indicates that income inequality between nations has a significant impact on emissions (Coondoo & Dinda, 2008), even whilst there has been a reduction in emission inequality between countries as manufacturing has shifted (Grunewald, Jakob & Mouratiadou, 2014). In general, whilst the exact socio-economic factors that affect emission can be complex (Büchs & Schnepf, 2013), there is strong evidence that economic inequality drives higher environmental impacts (Berthe & Elie, 2015).

Grunewald et al. (2017) undertook an econometric analysis using a 156-country panel dataset to consider the impacts of GDP and Gini on non-AFOLU national emissions over the period 1980 to 2008. The study concluded that there is a U-shaped relationship between emissions and inequality, but that it is dependent on the mean GDP. This implies that reducing inequality in poor nations may well reduce the net national emissions up to a certain point, after which point increasing wealth increases emissions.

Rao and Min (2018) modelled the potential outcome of a rapid decrease in global income inequality in line with the two most disparate equity pathways within the climate research Shared Socioeconomic Pathways (O'Neill et al., 2014). Their model estimated a net global reduction in emissions intensity of 9.5% compared to an inequitable pathway, driven by rapid decoupling in large growing economies. Emissions nevertheless grow over the modelling period because of faster GDP growth, and would only be offset if there is convergence in global incomes – a challenging policy goal.

The conclusions of both Grunewald et al. (2017) and Rao and Min (2018) are single studies, and so drawing broad-reaching conclusions from these may be premature without additional evidence from other sources.

2.2.2.2 Wealth inequality in South Africa

South Africa's levels of income and wealth inequality are high, with nearly 56% of the population falling below the upper bound poverty line in 2015 (StatsSA, 2017a). The Gini index measures inequality, with a value of 1 implying perfect inequality (a single percentile capturing all the measured variables) whilst a value of zero implies perfect equality. For income, RSA's 2014 Gini is estimated at between 0.63 (World Bank, 2016) and 0.68, down from 0.72 in 2006 (StatsSA, 2017a), making RSA the most unequal nation in the world. Wealth inequality is much higher, with Orthofer (2016) estimating a Gini of 0.95, implying that half of all wealth is held by the top 1%, and 90 to 95% is owned by the top decile. This is higher than many other unequal nations, not for the lower 50% which has a vanishingly small share of wealth even in wealthy nations (Piketty, 2014), but rather in the aggregation of wealth in the top decile (Orthofer, 2016).

It has been proposed that South Africa effectively has two parallel economies. President Thabo Mbeki famously stated that the first economy is "*modern, produces the bulk of our country's wealth, and is integrated within the global economy*", whilst the second is "*characterised by underdevelopment, contributes little to the GDP, contains a big percentage of our population… and is incapable of self-generated growth and development.*" (Mbeki, 2003). Whilst SA's pre-1994 history of racial segregation and differential access to resources under colonialism and apartheid is key to such inequality, the rate of wealth accumulation accelerated in the post-apartheid neo-capitalist era, with in-group inequality increasing and between-race inequality decreasing (Leibbrandt, Finn & Woolard, 2012). Although government policy aims to reduce poverty and inequality (NPC, 2012), poverty rates have showed no significant improvement since 1998.

National political and social dialogue strongly supports poverty reduction as one of the primary goals of national governance, with most other goals either linked or strongly subsidiary to this outcome. Whether such an approach will support mitigation goals depends on whether it can be pursued in a low carbon manner, and on structural issues specific to South Africa.

2.3 Literature analysing household level emissions

Many studies examine household energy consumption (Jones & Kammen, 2011; Cox et al., 2012; Guo et al., 2018), although fewer explicitly examine the impacts of income inequality. Such analyses are critical for an understanding of the effects of inequality and income distribution on emissions. Piketty & Chancel (2015) demonstrated that within-country inequality is increasing globally, rising from one third of all global inequality in 1998 to one half in 2013. They further estimate that South Africa is responsible for 2% of the emissions from the top 10% of individual global emitters, which is significantly larger than its roughly 1% national share of total global emissions (Kemp-Benedict et al., 2017). This implies a significant inequality in outputs from different income groups within the country.

To assess this intra-national inequality in emissions, many studies make use of input-output energy analysis (IO-EA) (Irfany & Klasen, 2016; Xu, Han & Lv, 2016; López et al., 2017). IO-EA correlates national sectoral energy consumption with the input-output tables provided as part of national accounts and can be refined by integrating data from household expenditure studies. This consumption-based analysis (IO-EA-Consumption) allows the tracking of both direct and indirect emissions (Kok, Benders & Moll, 2006). Differentiating consumption into income classes, or using expenditure as a proxy for income, enables the correlation of household emissions to income.

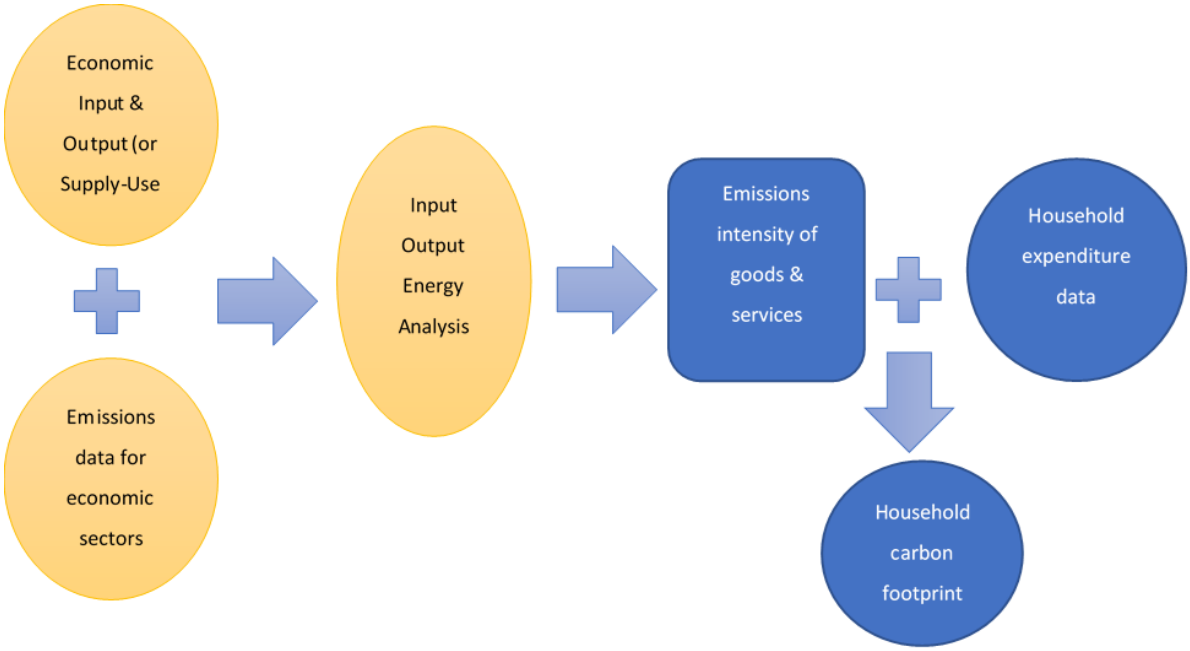

Figure 1: Determination of household carbon footprints by input-output emissions analysis combined with consumption data. [Source: modified from Irfany & Klasen (2017)]

The reliance on national energy balances means that non-energy emissions are not accounted for under these analyses. For countries with high forest stocks or high levels of land-conversion this can comprise a large portion of national emissions. For South Africa, where emissions are disproportionately from fossil fuel combustion (RSA, 2019a), this gap is less important.

Accounting for imports and exports in IO-EA can be challenging (Peters & Hertwich, 2008; Davis et al., 2018), particularly when considering complex technical imports whose footprint can be spread over several nations (Peters, Davis & Andrew, 2012). In most cases the carbon intensity of imports is either approximated through averaging trade balances, or is assumed to be the same as for domestic products (Arndt et al., 2013). Since South Africa has a very carbon intense economy this may overestimate total national emissions, but without accurate tracking of import purchases, the specific impact on household inequality is hard to measure. A recent analysis of Spanish household carbon footprints demonstrated that the increased emission intensity of high income households was driven largely by their higher share of energy intensive imports (López et al., 2016).

Some essential IO-EA studies have been undertaken for Brazil (Cohen, Lenzen & Schaeffer, 2005), China (Wiedenhofer et al., 2017), Indonesia (Irfany & Klasen, 2016), and South Africa (Arndt et al., 2013), as detailed below.

Cohen et al. (2005) used Brazilian IO accounts and energy balances for 1995 combined with a consumer expenditure survey to analyse household energy demand. Emissions increased with household income, with utilities, mobility and shelter dominating the energy requirements. A key outcome was the determination of a high expenditure elasticity of energy demand for direct consumption, with an

increasing propensity to consume fuel for mobility with increasing income. The study also determined that the expenditure elasticity for indirect energy emissions (embedded energy in goods and services) was generally low. The study examined only a single period, which did not allow for temporal trend analysis.

Irfany & Klasen (2016) used an IO-EA-consumption approach to analyse household-level emissions in Indonesia, and examined levels of energy and income inequality by constructing Gini and Thiel indices. By examining two points in time (2005 and 2009) a measure of the change in inequality and emissions could be obtained. They found that expenditure was a strong driver of emissions, with the most affluent quintile responsible for 46% of emissions, increasing to 47.6% over four years. They also found that emission inequality followed a general U shape, with the highest in-group differences in the first and fifth quintiles – possibly because of the unconstrained tails of these classes. Whilst overall emissions inequality was higher than expenditure inequality, emissions intensity reduced with increasing income.

Weidenhofer et al. (2017) made use of detailed Chinese I-O tables combined with a Multi-Regional Input-Output Model. National-level consumption data enabled disaggregation of household data with 8 urban and five rural income groups. The study established that household emissions strongly corresponded to expenditure; the carbon footprint elasticity of non-poor urban households was generally below one, whilst rural households averaged 1.12. The income-related disparity agrees with other findings that the marginal propensity to emit is inversely related to income (Duarte, Mainar & Sánchez-Chóliz, 2012), but interestingly, the trend is reversed in rural areas. The comparison of two time periods (2007 and 2012) showed decreasing inequality, and a corresponding decrease in household emissions over the period.

For South Africa, the seminal study is Arndt et al. (2013) and this thesis replicates the same approach to update this work. Rather than I-O tables, this thesis makes use of the disaggregated supply and use tables (SU tables) provided by the national statistics agency, together with energy balance and household consumption survey data. The use of SU tables enables the differentiation of product and sectoral carbon intensity, which facilitates better analysis of embodied carbon in products.

The Arndt et al. (2013) study provides valuable insights into sectoral and product carbon intensity, but for purposes of this thesis, household-level analysis is most pertinent. As with other country studies, overall carbon footprint increases with increasing expenditure, with overall household footprint being dominated by upper income deciles. The authors point out that the carbon footprint of the 96-100% percentiles is roughly equivalent to that of Kuwait (the second highest national footprint in the world), with interesting implications for intranational mitigation policy. Higher income percentiles also have much higher transport and accommodation service footprints, whilst the lower 60% percentile's footprint is dominated by food, agriculture, and textiles. Carbon intensity peaks in middle-income

brackets and declines for the highest income households, implying some form of EKC function due to increased use of modern energy forms and services in the top percentiles.

A key limitation of the Arndt et al. (2013) study is that it represents a single point in time (2005), which does not give any sense of the trend in carbon footprint and inequality. This gap will be filled by this thesis, whilst developing measures of household fair shares that might guide national mitigation policy processes. The following chapter details the data sources and methodology undertaken to conduct this analysis.

CHAPTER 3: METHODOLOGY AND DATA

This thesis analyses the impact of household consumption on national emissions and evaluates differences in household emissions with respect to income and consumption. To adequately estimate household consumption, it is necessary to integrate several different datasets.

This thesis originally proposed to use South Africa's national greenhouse gas inventory data published to the UNFCCC (RSA, 2014, 2017, 2019a), which provides a high level of disaggregation of data. Integrating this with long-term cohort studies from the National Income Dynamics Study (SALDRU, 2018) could consider household emissions in light of longitudinal data on demographic mobility. Consideration of longitudinal data might provide a good complementary analysis to the current thesis. However, the GHG Inventory data was unfortunately unavailable. This thesis makes use of the best data available, which is adequate for the proposed objectives.

This thesis follows the method outlined by Arndt *et al.* (2015) to derive carbon intensity measures (CIMs) from supply and use tables for a single year. It expands on this preliminary investigation by investigating household emissions in three years over a decade – 2005, 2010 and 2015. This enables analysis of changes in key variables over time, a critical element in determining climate mitigation responsibility. The years were selected based on available data – specifically household income and expenditure surveys conducted by the national statistical agency, StatsSA. In addition, the thesis uses household emissions and income data to construct measures of household inequality and mitigation burden.

In undertaking an assessment of the carbon intensity of South Africa's economy in 2005, Arndt *et al.* (2013) combined supply and use data in to a matrix (supply-use table, or SUT) together with data from the Department of Energy in the form of published energy balances. Integrating household consumption data provided a snapshot of household emissions and intensity. For purposes of SUT analysis, it is assumed that the supply and consumption of products by different activities is endogenous (i.e. within the SA economy), whilst tax, imports and exports, labour and profit margins are exogenous.

3.1 —Multiplier analysis

Input-output (IO) analysis is an economic tool for countries to construct their SNA and analyse flows of GDP. Leontief (1970) linked environmental data to IO analysis in order to estimate the impacts of changes to the economy on environmental externalities. This thesis uses multiplier analysis to establish the respective environmental (emissions) footprint of households.

A basic schematic of an IO table is shown in Figure 2 below. All industries are assumed to have a single homogenous product, which simplifies analysis. Supply and use tables are the basic tables from which

IO tables are constructed and differ in that they differentiate products and industries. The same multiplier analysis approach is used for both, so this chapter briefly describes the simpler IO analysis before moving on to SU analysis.

		Account receiving payment		
		Industry 1 ... Industry *n*	**Demands**	**Total**
Account making payment	**Industry 1 ... Industry *n***		Final demand (F_m)	Product demand (x_m)
	Taxes	Net taxes on products		
	Value-added	Gross value add (W_n)		
	Total	Total Output		

Figure 2: Schematic input-output table. All industries are assumed to have a homogenous product, simplifying analysis. Final demand includes households, government, import and export, capital formation and changes in inventories. Gross value add includes wages, gross operating surplus and non-production taxes and subsidies. [Source: own analysis, based on Arndt et al. (2013)]

3.1.1 Input-output analysis

The basic Leontief solution for IO analysis of an economy with n sectors each producing a homogenous product is:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \qquad (1)$$

where:

$\mathbf{x}$ = an $n \times 1$ vector of sectoral gross outputs

$\mathbf{I}$ = an $n \times n$ identity matrix

$\mathbf{A}$ = an $n \times n$ matrix of coefficients showing the intermediate inputs for each sector per unit of outputs; and

$\mathbf{f}$ = an $n \times 1$ vector of final demands.

The term $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix, a set of coefficients that describe for each sector the linkages to all other sectors (Miller & Blair, 2009). Since each sector is an intermediate user of other sectoral outputs (such as the steel industry, which uses iron and coal, but also produces steel that goes into mining equipment). Multiplier analysis effectively enables an understanding of a change in demand or a new tax on one product or industry as it ramifies throughout the economy. This highlights all

upstream effects for a given product. For instance, a fridge requires steel, plastic and electricity (amongst others) to produce. As such, the impact of the product proportional to the summed amount of impacts for each upstream component. For households, multiplier analysis thus enables a quantification of both the direct emissions from consumed fossil fuels, and the indirect emissions associated with the manufacture of household products. The ability of the Leontief inverse matrix to expose these indirect effects is critical for this study, and environmental multiplier analysis makes use of this technique, as described below.

3.1.1.1 Using IO tables for analysis of CO2 emissions

Multiplier analysis can be used to assess CO_2 emissions, as outlined by Arndt *et al* (2013). We first compile an $n \times 1$ vector $\mathbf{c}$ that reflects the economy's total fossil fuel emissions, obtained by multiplying energy balance data by the fossil fuels' respective emissions per unit of energy. This vector has values for coal, oil, and gas, and zero for all other products and industries. Using an $n \times n$ matrix $\hat{\mathbf{x}}$ with elements of $\mathbf{x}$ on the diagonal such that:

$$\hat{\mathbf{x}} = \mathbf{I} \cdot \mathbf{x} \qquad (2)$$

we can multiply to obtain a vector $\mathbf{e}$ of CO_2e emissions per unit of gross output for each fossil fuel:

$$\mathbf{e} = \hat{\mathbf{x}}^{-1}\mathbf{c} \qquad (3)$$

In effect, this divides the total emissions for each fossil fuel by the SU expenditure, giving a vector with values only for the three fossil fuel products.

Total emissions for the economy can be obtained as:

$$\mathbf{C} = \mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \qquad (4)$$

where:

$\mathbf{C}$ = an $n \times 1$ vector of emissions per sector; and

$\mathbf{e}'$ = the transpose of $\mathbf{e}$, to provide emissions as an input to the model.

$\mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}$ is therefore a $1 \times n$ vector, each element of which shows the carbon intensity of the sector, measured in emissions per unit expenditure (tCO_2e /R '000). This is termed the carbon intensity measure (CIM).

3.1.2 Supply-use approach

IO tables' conflation of products and sectors is valuable at an economy-wide level, and is frequently used for analysis of international trade (Su & Ang, 2010). SU tables, however, can provide a differentiation between product and sectoral carbon emissions because of their disaggregation. Arndt *et al*. (2013) propose that SUT analysis provides better differentiation of CIMs for complex economies such as SA's. For household-level analysis, SUT analysis allows a finer distinction of the relative footprint from consumption of disaggregated products.

SUT multiplier analysis assumes the economy has a differing number of products (m) and industries (n). The supply table ($\mathbf{D}$) is an $n \times m$ matrix showing final deliveries of products by industries, whilst the use table ($\mathbf{Z}$) is an $m \times n$ matrix of intermediate consumption of products by industries. Final demand, taxes, factor inputs (wages), and imports are assumed to be exogenous, whilst the gross output, total industry supplies, intermediate inputs and domestic sales by industries are endogenous.

		Account receiving payment				
		Industry 1 … Industry *n*	**Product 1 … Product *m***	**Margins**	**Demands**	**Total**
Account making payment	**Industry 1 … Industry *n***		Sales by domestic industries (D_{mn})			Industry supply (x_n)
	Product 1 … Product *m*	Intermediate inputs (Z_{mn})		Margin products	Final demand (F_m)	Product demand (x_m)
	Margins		Transaction margins			
	Value-added	Factor inputs (W_n): GOS & wages				
	Taxes	Net taxes on production	Net taxes on products			
	Imports		Imports (Mm)			
	Total	Gross output	Product supply			

Figure 3: Schematic supply-use table. [Source: Arndt et al., 2013]

An integrated SUT is constructed (Figure 3), with endogenous factors represented in matrix terms as:

$$\begin{bmatrix} \mathbf{x}_n \\ \mathbf{x}_m \end{bmatrix} = \begin{bmatrix} \mathbf{0} & \mathbf{D} \\ \mathbf{Z} & \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} \\ \mathbf{f} \end{bmatrix} \quad (5)$$

where:

$\mathbf{f}$ = an $m \times 1$ vector of final exogenous product demand;

$\mathbf{x}_n$ = a $n \times 1$ vector of final outputs by industries; and

$\mathbf{x_m}$ = an $m \times 1$ vector of total product supply (Arndt *et al*, 2013).

As with IO analysis, we then determine a coefficient matrix **B**, now separated over for products and industries:

$$\mathbf{B} \equiv \begin{bmatrix} \mathbf{0} & \left\{\frac{\mathbf{d_{ij}}}{\mathbf{x_i}}\right\} \\ \left\{\frac{\mathbf{z_{ij}}}{\mathbf{x_j}}\right\} & \mathbf{0} \end{bmatrix} \boldsymbol{i = 1 \ldots m; j = 1 \ldots n} \qquad (6)$$

where:

$\mathbf{d_{ij}}$ = industry j's production of product i;

$\mathbf{z_{ij}}$ = industry j's consumption of product i;

$\mathbf{x_i}$ = final output of industry j; and

$\mathbf{x_j}$ =total supply of product i.

Substituting into Equation (5) above, we get:

$$\mathbf{x = Bx + f} \qquad (7)$$

and the Leontief solution is:

$$\mathbf{x = (I - B)^{-1} f} \qquad (8)$$

3.1.2.1 Using SU tables for analysis of CO_2 emissions

Since industry demands and product demands are not equal, it is necessary to scale the Leontief matrix such that the diagonal elements are equal to one.

As with IO analysis, multiplying the scaled elements by the vector of carbon dioxide emissions $\mathbf{e'}$, we can derive a vector of unit total emissions for each product $\mathbf{C}$ as:

$$\mathbf{C = e'(I - B)^{-1} f} \qquad (9)$$

where:

$\mathbf{e'}$ is a vector $[0\ \mathbf{ec'}]$, with 0 for all n activity elements, and a $1 \times m$ vector of emissions for all energy products, derived by applying equations **(2)** and **(3)** to the vector $\mathbf{x_m}$ in Equation (5); and

The $1 \times (n + m)$ vector $\mathbf{e'(I - B)^{-1}}$ represents the SU table CIM for both industries and products.

*3.1.2.2 To calculate **household CIMs,** the total SU household demand is first divided proportionally per product in line with household expenditure shares from the LCS/IES datasets (see Limitations*

Supply-use analysis assumes that the coefficients derived in B above are invariate, and that prices are fixed. This assumption is critical for multiplier analysis, translating changes in consumption to proportional upstream effects. Since prices vary with demand and coefficients differ from year to year, these assumptions are limiting. In addition, the standard I-O assumption of standard prices per aggregate product is typically only valid within limits: high-income households may pay a premium for preferred brand products with a similar environmental footprint. A consequence of this assumption is that the footprint of such high-income households is overestimated in the model. Nevertheless, S-U analysis provides a simple means of approximating economic and environmental impacts for a given period of time.

Household analysis below). This provides a $m \times 1$ vector of disaggregated consumption per product for each household class. The vector can then be multiplied by the CIMs product vector to produce a CIM for each household class.

It should be noted that this model only considers fossil fuel emissions and not AFOLU, IPPU or waste emissions. Total household emissions are therefore underestimated, especially for lower-income and rural households with higher non-fossil energy dependencies. However, since fossil fuel combustion accounts for 74% of national GHG (RSA, 2019a), it is a valuable proxy for total emissions.

A key difference between IO and SU analysis is the degree of disaggregation within the products, and the ability to see economy-wide impacts more clearly through endogenous demand. This thesis uses SUT analysis to obtain a more accurate assessment of the GHG emissions embedded in specific products for household analysis.

3.1.2.3 Limitations

Supply-use analysis assumes that the coefficients derived in B above are invariate, and that prices are fixed. This assumption is critical for multiplier analysis, translating changes in consumption to proportional upstream effects. Since prices vary with demand and coefficients differ from year to year, these assumptions are limiting. In addition, the standard I-O assumption of standard prices per aggregate product is typically only valid within limits: high-income households may pay a premium for preferred brand products with a similar environmental footprint. A consequence of this assumption is that the footprint of such high-income households is overestimated in the model. Nevertheless, S-U analysis provides a simple means of approximating economic and environmental impacts for a given period of time.

3.2 Household analysis

South Africa's highly unequal economy (Orthofer, 2016) means that per capita expenditure is much higher in upper income percentiles, and varies more within the top decile than between many lower income deciles. To enable comparisons in these higher income groups, the dataset was disaggregated into 14 different groupings as outlined in Table 1.

Household income/expenditure group	Percentile of population captured in group
1	0-10%
2	11-20%
3	21 - 30%
4	31 - 40%
5	41 - 50%
6	51 - 60%
7	61 - 70%
8	71 - 80%
9	81 - 90%
10	91 - 92%
11	92 - 94%
12	95 - 96%
13	97 - 98%
14	99 - 100%

Table 1: Population percentiles of household groups studied.

These household groupings are defined for both per-capita household income (pc_inc) and expenditure (pc_exp) from the StatsSA IES/LCS surveys. Since income correlates more closely to capability, and expenditure-linked emissions to responsibility, this allows an assessment of on the impact of each on emissions inequality and mitigation fair shares, as well as construction of an integrated fair share measure that combines both capability and responsibility. Household per capita measures are calculated by dividing total household income/expenditure by household size; per-capita measures correct for the impact of shared income with varying household sizes. It should be noted that averaged values for household groups may not adequately explain within-group diversity of expenditure and income, but for purposes of this thesis it allows analysis of trends between groups.

3.2.1 Inequality

Two measures of inequality are used in assessing income, expenditure and emissions equality across household groupings; the **Gini coefficient** (Gini, 1921) and the **Palma ratio** (Palma, 2011). The Gini index is the most common index of inequality. Ranging from 0 (perfectly even distribution) to 1 (all

wealth/income attributable to a single individual), this measure is insensitive to extreme outliers, but gives a reasonable indication of trends and broader structural inequality.

The **Palma ratio** is calculated as the multiple by which the most affluent 10% of the population exceeds the income of the lowest 40%. It is largely insensitive to distribution in the median income bands but gives a better sense of the disproportional distribution at the outer edges of the income distribution.

These two measures therefore give a complementary perspective on structural inequality for a given indicator. In this research, both indices are examined.

The Gini coefficient is calculated as the area under the Lorenz curve (cumulative national income from 0 to 1 on the y axis and ranked income/expenditure deciles on the x axis); this is unknown *ex ante*. Gini is therefore evaluated using a trapezoidal approximation of ranked incomes per household grouping (Teng et al., 2011):

$$\mathbf{G = 1 - \sum_{k=1}^{n} (X_k - X_{k-1})\,(Y_k + Y_{k-1})} \qquad \mathbf{(10)}$$

where:

$(\mathbf{X}_k, \mathbf{Y}_k)$ are the known values on the Lorenz curve, such that:

$\mathbf{X}_k$ is the cumulated proportion of the population variable ranked in increasing order, for $k = 0, \dots, n$, with $\mathbf{X}_0 = \mathbf{0}, \mathbf{X}_n = \mathbf{1}$;

$\mathbf{Y}_k$ is the cumulated proportion of the income variable ranked in non-decreasing order, for $k = 0, \dots, n$, with $\mathbf{Y}_0 = \mathbf{0}, \mathbf{Y}_n = \mathbf{1}$.

The Gini coefficient is insensitive to changes at the top and bottom of the income distribution and does not capture where in the income distribution such inequality occurs. In order to evaluate the specific inequalities between outlying deciles, this thesis also makes use of the **Palma** ratio (Palma, 2011). This measure is more sensitive to distributional changes in the outer deciles, being calculated as the ratio of the top income (or expenditure) decile's share of income to the poorest 40%'s share:

$$\boldsymbol{P = D_{10} \Big/ \sum_{n=1}^{n=4} D_n} \qquad \mathbf{(11)}$$

where:

$\mathbf{D}_n$ is the *nth* decile of the population by income (or expenditure).

For each measure, and household group, income inequality measures are constructed using the average per capita income for the respective household groups. For emissions and expenditure, the average expenditure per SUT for each household group was used, and in the case of emissions multiplied by the CIM for the respective SUTs to arrive at average emissions totals for each group.

3.2.2 Fair shares

Household fair shares are calculated for the year 2015. Responsibility for each household group ($\mathbf{R_{Hi}}$) is assessed as average per capita household emissions for each household group as a proportion of total household emissions.

$$\mathbf{R_{Hi}} = \boldsymbol{E_{Hi}} \Big/ \sum_{\boldsymbol{i=0}}^{\boldsymbol{i=n}} \boldsymbol{E_{Hi}} \qquad \textbf{(12)}$$

where:

$\boldsymbol{E_{Hi}}$ is the average household emissions for household group $\boldsymbol{i}$; and

$\boldsymbol{n}$ is the total number of household groups (14).

Total responsibility for the top decile can thus be assessed as the sum of the top 5 household groups, whilst all other responsibility measures are for distinct deciles.

A simple capability measure ($\boldsymbol{C_H}$) for each household is calculated using the same calculation for household income instead of emissions.

$$\boldsymbol{C_{Hi}} = \boldsymbol{I_H i} \Big/ \sum_{\boldsymbol{i=0}}^{\boldsymbol{i=n}} \boldsymbol{I_{Hi}} \qquad \textbf{(13)}$$

where:

$\boldsymbol{I_{Hi}}$ is the household income for group $\boldsymbol{i}$; and

$\boldsymbol{n}$ is the total number of household groups (14).

Again, total capacity for the top decile can be calculated as the sum of the top five responsibility values, whilst all other $\boldsymbol{I_{Hi}}$ are mean capacity per income decile.

The Climate Equity Reference Calculator (CERC) (Kemp-Benedict et al., 2017) in line with Holz et al. (2017) has been used by civil society internationally, and within South African national civil society

(Van Zyl et al., 2018). The CERC proposes a baseline earning rate of US$ 7,500 as the per capita default development threshold, below which individuals have no capability to address climate action. This value is corrected for purchasing power parity (PPP) (OECD, 2019) and used as a minimum measure of capability, giving rise to two additional fair share assessments. The first is a threshold capability measure, in which only those households with income above the threshold carry a burden proportional to the household group's share of national above-threshold income.

$$\boldsymbol{CT_{Hi}} = \mathbf{max(0, I_{Hi} - T)} \Big/ \sum_{\boldsymbol{i=0}}^{\boldsymbol{i=n}} \mathbf{max(0, I_{Hi} - T)} \qquad \mathbf{(14)}$$

where:

$\boldsymbol{CT_{Hi}}$ is the individual threshold capability measure for household group $\boldsymbol{i}$;

$\boldsymbol{n}$ is the total number of household groups (14); and

T is the threshold value of $7500 PPP.

A final combined household fair share measure ($\boldsymbol{FS_{Hi}}$) the product of the household responsibility measure and threshold capability measured as a fraction of the sum of such products:

$$\boldsymbol{FS_{Hi}} = (\mathbf{CT_{Hi}} * \mathbf{R_{Hi}}) \Big/ \sum_{\boldsymbol{i=0}}^{\boldsymbol{i=n}} (\mathbf{CT_{Hi}} * \mathbf{R_{Hi}}) \qquad \mathbf{(15)}$$

where:

$\boldsymbol{n}$ is the total number of household groups.

The measure uses the product of $\mathbf{CT_{Hi}}$ and $\mathbf{R_{Hi}}$ to preserve the development threshold, excluding all households with a mean annual income below the developmental threshold. The combined measure assigns the overall burden amongst all other income deciles, equally balancing their respective responsibility and capability. This approach is consistent with development threshold's intention of limiting mitigation to those for whom basic develomental needs are addressed.

3.3 Data sources

Supply and use tables prepared by StatsSA for the years 2005, 2010 and 2015 are the primary data source for the thesis (StatsSA, 2010, 2013, 2019a).

For the reporting year of 2005, StatsSA provided SU tables in the form of 104 products and 171 industries, according to the 1993 system of national accounts (SNA). In 2014 the activities were consolidated to 64 industries. To enable comparison of the datasets from different periods, it is necessary to consolidate the 2005/6 IES data to reflect the same activity breakdown as for the latter periods. This is achieved by establishing equivalencies for each of the industries to relevant Central Product Classification (CPC) codes using conversion tables published in the system of national accounts (StatsSA, 2010, 2015). One challenge of this approach is that nuclear fuels (SIC group 333) transitioned from petroleum industries in the 104-171 classification to a grouping with basic chemicals, whilst petroleum refining and coking were aggregated into the new grouping I17. For these cases, the specific allocation per industry is undertaken using product-level breakdown rather than SIC equivalencies, assuming that the majority of electricity generation expenditure on petroleum industries was on nuclear fuel (Pauw, 2007). This assumption should be valid prior to 2007, when South Africa first introduced 2GW of Open Cycle Gas Turbines that use diesel.

A natural gas sector is also introduced to allow for disaggregation of the primary fossil fuels, as per Arndt et al. (2013). Natural gas is separated from the "Other mining products" grouping in SUT, with all the electricity industry's expenditure on other mining attributed to gas turbines (Pauw, 2007). Most gas consumption is endogenous, with minimal household consumption, but the disaggregation is essential to enable accurate attribution of emissions in final products.

3.3.1 Energy data

Energy data is sourced from the Energy Balance (EB) data published on the Department of Energy website (DoE, 2018; DMRE, 2019), as well as the SU data (StatsSA, 2012a). CO_2 balance data was not available for all years from the DoE, and consequently direct energy consumption figures are used. However, the sectoral allocation of EB data differs from that of the SU expenditure. To transform the EB data (physical units - GJ) into SU (financial - R) units and integrate them into the SUT, energy prices (Rm/GJ, or million Dec 2016 Rand per gigajoule) are calculated for the primary fossil fuels. For coal, this is done based on EB energy amounts and SU prices. For oil and gas, disaggregated SU prices are not directly available, so import and retail prices from the Energy Price reports (DME, 2006; DoE, 2011, 2017) are used. In addition, since oil prices are reported in dollars per barrel, price per TJ was calculated using the calorific value (42.3 GJ/t) (UNSD, 2020) and density (856 kg/m3) of crude oil.

To align the data, it is assumed that the SU tables accurately describe activities' relative expenditure and supply of the identified products. In line with Arndt et al. (2013) we further assume that the EB's absolute energy volumes are correct. EB values for imports, exports, stock changes, final demand, domestic production, and transformation sectors (coal-to-liquids, petroleum refineries, gas-to-liquids, and electricity generation) are retained. Since the EB describes total, not sectoral, consumption, the

remainder of the intermediate demand is assigned proportional to the original SU expenditure shares. This ensures that the SU price and EB energy volumes are both reflected.

A further change to the SUT is made to reflect the national electricity provider Eskom's sectoral pricing. Eskom's annual reports (Eskom, 2005, 2010, 2016) identify electricity volumes and total revenue for different sectors, enabling effective price calculations (R/kWh and R/GJ). Since multiplier analysis assumes that all sectors pay the same price for a product, the base price is calculated for all Eskom pricing sectors by dividing SU electricity price by total EB electricity volume. Whilst Eskom's sector delineations do not equate directly to the SIC classes, an equivalency for each class was established to enable the determination of effective prices for each SU activity as a proportion of the base price. In the SUT, then, all endogenous electricity sales volumes are calculated using the base price, with sectoral price variations recorded as an effective exogenous tax (or subsidy) on the product. Total sales volumes remain as per the SU tables.

Finally, default emissions for each fossil fuel type are obtained from literature[3]. Combined with EB data, this enables the construction of the emissions vector $\mathbf{c}$ with values of zero for all products except the three fossil fuel types. This vector is in turn used to estimate the total indirect and direct emissions for each product as described in Equation **(9)**,

3.3.2 Household data

Household consumption data is sourced for 2005/6 and 2010/11 from the Income and Expenditure Surveys (IES) undertaken by Statistics South Africa (StatsSA, 2008, 2012b). These comprehensive surveys enable analysis of expenditure patterns in different areas and demographics across the country. Compiled from in-depth interviews and household expenditure diaries, the surveys form the basis for the consumer goods basket used by Statistics South Africa in calculating Consumer Price Index (CPI). It is possible to use these datasets to assess mean expenditure on different products for each household income group.

No IES was conducted in 2015, so the Living Conditions Survey (LCS) of 2014-2015 is used (StatsSA, 2017b). This dataset replicates the basic IES data regarding income, consumption, and per-product expenditure, although additional questions in the survey are used to assess a broader living conditions mandate. The SU tables reflected some household expenditure for products not reported in the IES/LCS;

[3] Emissions factors: coal 96.02 tCO_2e/GJ (IPCC, 2018b), oil 74.35 tCO_2e/GJ and gas 56.10 tCO_2e/GJ (RSA, 2017).

for these products, the mean per-household group expenditure weighting for all products in the relevant IES/LCS study was used[4].

To enable tracking of expenditure by SUT class, Classification of Individual Consumption by Purpose (COICOP) codes were aggregated to SU product classes using COICOP-CPC equivalences from StatsSA. Household consumption vectors for the multiplier analysis comprise per-product weightings in line with the LCS/IES data, such that the total of all household consumption in each product class sum to one.

Whilst StatsSA notes a systematic difference between the COICOP expenditure reported in the IES/LCS studies and the large sample surveys used to compile the supply and use tables, all expenditure is within 5 to 7% of each other, with the exception of food, beverages and tobacco (StatsSA, 2016). Larger IES/LCS weights for the exceptional values above are driven by informal economy expenditure, which is not captured in large-scale retail studies. This thesis assumed that these expenditure differences are not significant, and consequently the overall expenditure per product class in the SU tables was apportioned according to the relative shares calculated for each household group.

Households with limited energy access in the IES contribute only to the assessment of indirect emission through product purchase. Since the model assesses only fossil fuel emissions, such households' emissions non-fossil (such as from biomass burning) may not be adequately tracked, contributing to a lowering of the total footprint for the lowest income classes.

Although survey data is notoriously challenging to use, these datasets have undergone curation and correction by StatsSA, simplifying their use considerably. The datasets include calculated weightings for households to address potential, over/under-sampling for given demographics, non-response errors, and adjustments for excluded enumeration areas with fewer than 25 households (StatsSA, 2012c). These weightings are applied in the establishment of household groups, and consequently in estimating expenditure data. Identification of household groups and evaluation of mean per capita income (including in-kind income, but not taxes) and per-product expenditure for each household group is undertaken in Stata Statistical Software (StataCorp, 2017), with an example of the data preparation code in CHAPTER 8:Appendix 4. All other calculations and evaluations are carried out in Excel (Microsoft, 2020).

[4] This change shifts the product composition of household expenditure to some extent. For instance, in 2015, this added leather, paint, plastic and ceramic products, as well as legal, accounting and other business services to the household expenditure lists. This better reflects expenditure within the SU tables.

3.3.3 Other data

Nominal prices are used for fuel, electricity, and household consumption to construct each SUT year model. To enable between-year comparisons, real prices were calculated using CPI data from StatsSA (StatsSA, 2019b), using Dec 2016 as the base year. The use of real prices changes and the change in sectoral attributions described above mean that absolute CIMs are not comparable to Arndt *et al.* (2013).

3.4 Summary of chapter 3

This chapter outlines the SUT approach used for multiplier analysis. SUT analysis provides a better analysis of household consumption than IO analysis, since it can correlate emissions more closely to specific household expenditure. It details all the datasets used in the model and analysis, as well as the process of calculating measures of household inequality and fair mitigation shares.

Having considered data and methods, chapter 4 will examine the results of the model.

CHAPTER 4: RESULTS

The research question outlined in Chapter 1 is to examine household fair shares of the national mitigation burden in relation to household inequality. This can be achieved by examining whether there is a correlation between household income and emissions over time. This is a crucial question when considering equity elements of climate mitigation policy, a central point of tension in international negotiations, and a key element of South Africa's international climate policy position. This chapter presents results from the application of the methods outlined in Chapter 3.

This thesis focuses particularly on emissions attributed to household expenditure, which is a significant portion of overall national emissions. Over the period studied (2005 to 2015), despite a gradual reduction in emissions intensity in South Africa, total household consumption emissions increased.

Household consumption reflected in this study differs from national GHG assessments in that the IPCC 2006 guidelines (IPCC, 2006) take a production- and combustion-based approach, which considers emission at the point at which it is emitted. This study rather follows a consumption-based approach, which considers emissions at the point of consumption. Exports cannot be attributed to households using a CB approach, but imports that are consumed at household level contribute to household emissions. The model assumes that imports have the same carbon intensity as locally manufactured products; whilst this is unlikely to be the case, full attribution of import carbon intensity is not possible with the current datasets.

4.1 Expenditure vs income classification

This thesis differentiates household classes by both per capita income (pc_inc) and per capita expenditure (pc_exp). Whilst expenditure is typically bounded by income, it is more often used in consumption analyses because expenditure better reflects consumption trends and avoids the broad in-class variation of income classes driven by variable savings rates. Income classes can nevertheless be particularly useful at a policy level, since reporting of income is required by tax authorities (at least above a minimum level), and therefore provides a useful immediate proxy for policy interventions. When drawing linkages to the UNFCCC concept of equity and CBDR/RC, either measure functions as a valid proxy for capability, although wealth is a better measure for the embedded concept of historical beneficiation. For purposes of inequality measures and household shares, therefore, both measures were used in this study.

4.2 Total emissions

Figure 4 shows trends in total household emissions, which increased 7.5% between 2005 and 2015, whilst total GDP CO_2 emissions increased by 0.4% over the decade. Household consumption's share

of the national emissions is therefore growing over time, whilst the overall emissions profile is not changing significantly, reflecting South Africa's limited decarbonisation of the energy sector over the period.

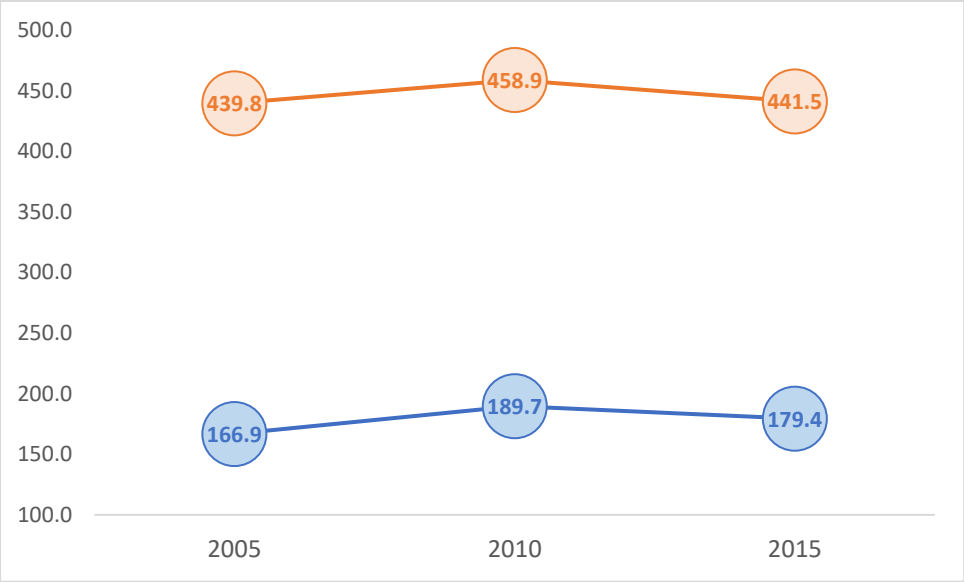

Figure 4: Change in total household emissions(blue) and total GDP emissions (orange) from 2005 to 2015 ($MtCO_2e$ per year) [Source: Own calculations from SUT model; fossil fuel data from Energy Balance]

Total emissions estimated by the SUT model described in Chapter 3 differ from those documented in the official National GHG Inventory for those years covered to date. As shown in Figure 4, the model estimates total GDP fossil fuel-related emissions for 2005 (including exports, with the exception of direct coal exports) were 439 $MtCO_2e$. The GHG inventory provides a net total of 494 $MtCO_2e$ for 2005 including all sources, but it cannot be disambiguated. Using a sectoral breakdown of estimated from the GHG inventory for 2012 (RSA, 2017) as a proxy for 2005 estimates we estimate 412.2 $MtCO_2e$ total carbon dioxide emissions, not including AFOLU. For 2010, the SU model estimates full absorption of emissions at 458.9 $MtCO_2e$, as compared with the GHG inventory estimate of 454.4Mt for CO_2 alone. For 2015, the model estimates net CO_2e emissions from fossil fuel consumption of 441.5 $MtCO_2e$, compared to 459.9 for CO_2 alone in the GHG inventory (RSA, 2019a).

These disparities may be attributed to the SU model's limited consideration of additional sinks and sources relating to agriculture, forestry and other land uses, as well as the exclusion of process emissions from several sectors: attribution in this model is limited to the combustion and consumption of the three main fossil fuels – coal, oil and gas. Whilst South Africa has abundant coal supplies, it has little domestic production of oil and gas, which are either imported or manufactured through cracking of coal.

4.3 Carbon intensity measures

To calculate household carbon intensity, we first model carbon intensity measures (CIMs) for sectors and products, measured as tonnes of CO_2e emitted per thousand Rand expenditure. Sectoral CIMs not considered here but relevant for targeted mitigation policy purposes are described in full in Table 5 in Appendix 1.

CIMs for the carbon intensity for products are shown in Table 2 below. These are aggregate products, largely distinct from those that might be purchased by a household. However, by linking actual household expenditure on specific COICOP purchases in the IES/LCS data to these aggregate products as outlined in Chapter 3, CIMs for all products and sectors are calculated.

	2005		2010		2015	
Rank	Product	CIM	Product	CIM	Product	CIM
1	Coal and lignite	4.740	Coal and lignite	3.374	Coal and lignite	3.296
2	Electricity distribution	1.640	Electricity distribution	1.332	Trade services	1.904
3	Electricity and gas	1.051	Electricity and gas	0.872	Electricity distribution	0.878
4	Crude oil	0.701	Crude oil	0.601	Natural gas	0.852
5	Natural gas	0.455	Natural gas	0.515	Crude oil	0.615
6	Trade services	0.350	Trade services	0.307	Electricity and gas	0.499
7	Petroleum products	0.332	Petroleum products	0.279	Petroleum products	0.264
8	Support services	0.180	Support services	0.177	Freight transport	0.135
9	Natural water	0.179	Natural water	0.154	Basic chemicals	0.128
10	Water distribution	0.176	Water distribution	0.148	Non-metallic products n.e.c.	0.113

Table 2: The top ten products ranked in terms of carbon intensity measure for the period 2005 to 2015. [Source: own analysis]

Coal is the most carbon intense product in the South African economy, with a 2005 CIM of 4.74, decreasing to 3.3 in 2015. Electricity generation and distribution both have high CIMs (generation emissions are attributed to both, because transmission losses are not adequately tracked in the SUT). Oil, gas, and petroleum products have unsurprisingly high CIMs, but natural water and water distribution are also high; this is a result of South Africa's artificially interconnected water catchment and management system, with pumped storage, large pipelines and high infrastructural investment. Trade industries and support services round out the top ten, although non-metallic manufactured products replace the latter in 2015. As with the industries, most products demonstrate a reduction in carbon intensity over the study period, as GDP grows, but national emissions remain stable.

Sector	2005	2010	2015
Total economy	0.109	0.094	0.077
Household Consumption	0.084	0.084	0.067
Government consumption	0.031	0.035	0.015
Gross fixed capital formation	0.044	0.045	0.031
Changes in inventories	0.425	-0.024	0.086
Exports	0.264	0.210	0.176
Imports*	0.128	0.130	0.104

*Table 3: Carbon intensity measures (tCO2e/R'000) of GDP and structural components for the whole economy. * Import carbon intensity assumes that source nations have the same emissions intensity as South Africa. [Source: own analysis]*

Table 3 shows the changes in carbon intensity of the economy over the study period. CIMs for most components decrease between 2005 and 2015, with exception of moderate gains in intensity for government consumption, fixed capital formation and imports in 2010. Overall, exports are the most carbon intensive sector of the economy, driven by the significant minerals component. The high inventory change CIM in 2005 is primarily driven by coal overproduction and stockpiling, and negative emissions intensity for inventory changes in 2010 reflects net reduction in inventory for multiple products. Overall reduction is indicative of a growth in GDP over the period, even correcting for inflation, with total emissions staying relatively constant. This may be evidence for the environmental Kuznets curve, although there is no indication that the trend will continue absenting policy intervention.

4.3.1 Household emissions intensity

Household CIMs were calculated by multiplying product CIMS by average household consumption per product, for each aggregate household grouping calculated as outlined in section 3.2. As shown in Figure 5 below, household emissions intensity decreased over the study period for all household groups. Emissions intensity for households in the upper 10% decile initially increase in 2010, then decrease by 2015. For all other income groups household carbon intensity decreases throughout. The pc_exp 98-100% top percentile bracket consistently demonstrates the lowest carbon emissions intensity, reflecting the relatively high investment in low-impact financial and service products. The spread in emissions intensity is higher for pc_exp than pc_inc, and the significant drop in overall household intensity is notable when compared to the economies moderate intensity reduction

Examination of expenditure trends per household between 2010 and 2015 illustrated some drivers of this trend. For all household groups, proportional electricity and transport expenditure increased (particularly for low income households), whilst these activities showed declining intensities. Expenditure on petrol and products from light and heavy industry dropped, and for the higher income

deciles (where the change was most pronounced) expenditure on low-carbon financial services increased.

Full decomposition of household carbon intensity by sector and grouped products is provided in Appendix 2.

Figure 5: Change in carbon intensity measures per for a) income and b) expenditure household groups over the study period. [Source: own analysis]

4.4 Inequality measures

Household inequality was measured for three different indicators: income, expenditure, and overall expenditure-related CO_2 emissions per household group. Household inequality was measured using the Gini index as well as the Palma ratio.

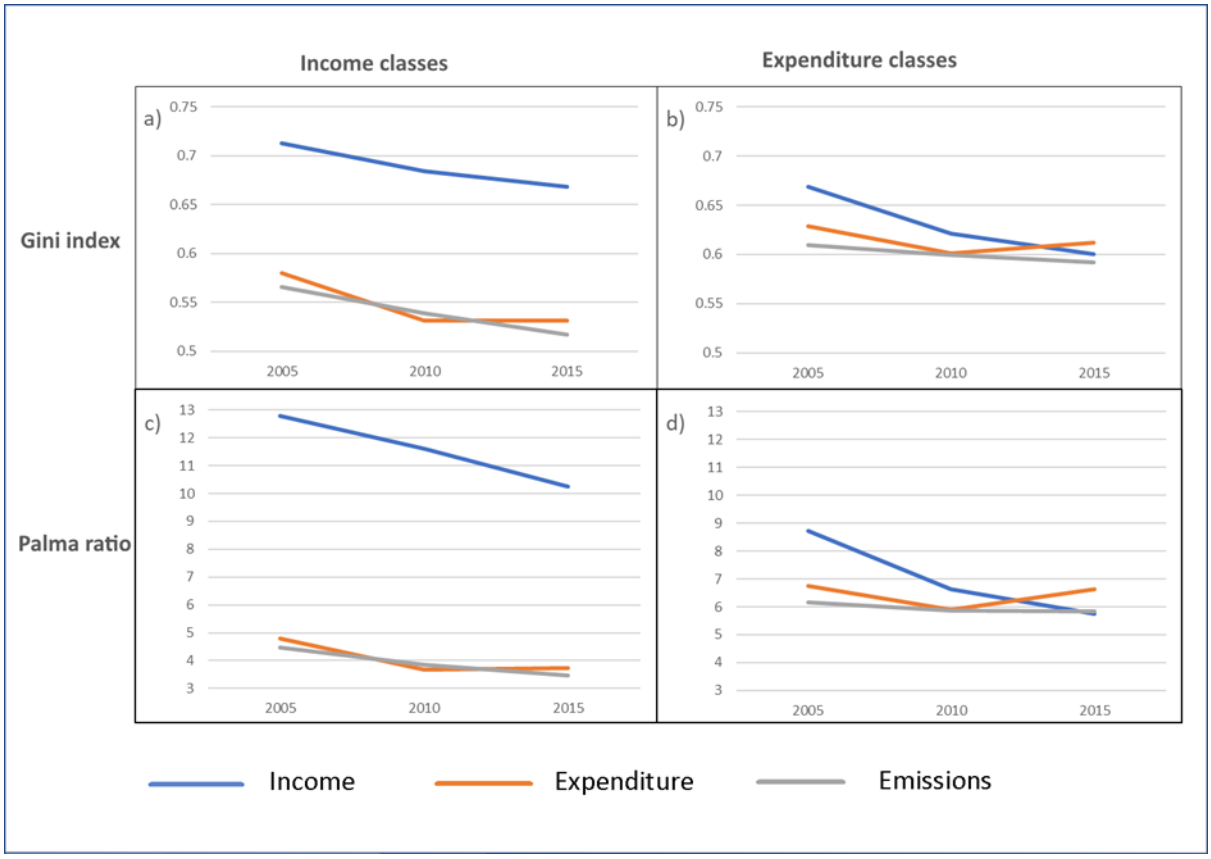

Figure 6: Change in inequality measures for all household classes 2005-2015. Inequality was calculated for income classes (a & c) and expenditure classes (b & d), with two measures (Gini index, a & b) and Palma ratio (c & d). [Source: own analysis]

Figure 6 above illustrates both Palma and Gini indices against income and expenditure categories.

Inequality is consistently higher for income than the other indicators, with emissions and expenditure closely tracking each other. Income inequality is particularly high in pc_inc where income is the determinant for household classification. However, over the study period (2005 to 2015) income inequality decreased marginally by both measures. The driver for this is unclear, but increased access to social support grants over the period may be a factor.

4.4.1 Palma ratios

The Palma ratio is calculated as the multiple by which the top decile exceeds the share of the bottom four deciles, and is more useful than Gini for developing nations because it better tracks changes in the shares of the outlying deciles. The top income decile in South Africa captures most of the income and is responsible for the majority of expenditure, with Palma ratios universally high for all measures.

Palma ratios drop between 2005 and 2010 for all measures except the expenditure shares of pc_exp, which drops in 2010 (from 6.8 to 5.9), and then recovers to nearly the same level (6.72). This exception

is notable, and appears to be driven by increased expenditure of high-income deciles on financial services over the period. As might be expected, income inequality is highest when households are classified by income (pc_inc), with a Palma ratio over 10.5 in 2015. Emissions inequality and expenditure inequality are lower than income equality for pc_inc, but for pc_exp they are close.

For the remainder of the thesis we categorise households by Palma group as well as household percentile, because these aggregate classes tend to exhibit the same trends.

4.4.2 Gini indices

Gini indices indicate the same trends as the Palma ratios, with inequality decreasing for all measures except the expenditure shares within the pc_exp group, where initial reductions in inequality by 2010 were overturned by 2015. Overall, reduction in inequality was stronger in the pc_inc household groups, but final Gini indices for all household groups and indicators remained high in 2015.

4.5 Consumption-based household emissions shares

The thesis now turns to reporting household carbon footprints of SA households across classes. GHG emissions are attributed to households, based on consumption (as explained in Chapter 3 above), and reported for both income and expenditure classes.

Shares of total household emissions per household class are shown in Figure 7 below. All deciles are illustrated, with the bottom Palma group in blue, the middle classes in green, and the top Palma group in brown/orange. Over the analysis period, the middle class (40-90% decile) share grows for both pc_inc and pc_exp. For pc_inc, the lower income (bottom 40%) decile share grow incrementally from 10% in 2005 to 12% in 2015. For pc_exp, however, it remains at 10% throughout.

The share of the national carbon emissions consumed by the upper decile (delineated in brown) therefore decreases over the analysis period (from 47% to 40% for pc_inc, and from 52% to 40% for pc_exp), with expanding middle-class consumption absorbing much of the reduction. The bottom 40% (in blue), by comparison, experienced proportional increase in emissions share. The reduction in Palma emissions inequality observed in Figure 6 above therefore reflects only a reduction in the total share of the top 10%, not an increase for the lower Palma group.

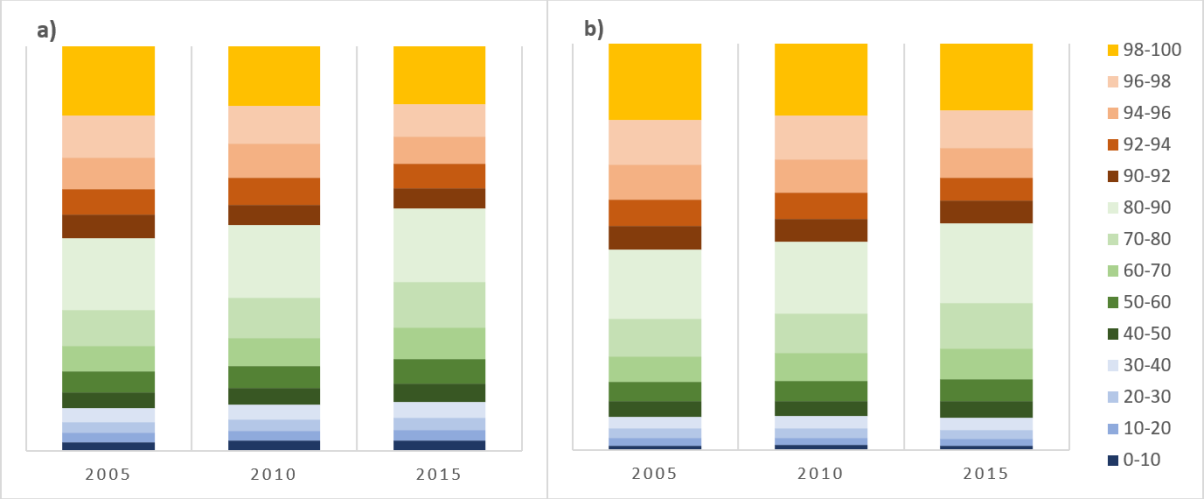

Figure 7: Shares of national emissions for each analysed household group, for both a) income classes and b expenditure classes, in 2005-15. All Palma ranking groups are indicated by colour (bottom 40%: blue; middle classes: green; top 10% brown/orange), whilst household classes are reflected by differentiation in shade. [Source: own analysis]

4.6 Per capita emissions

Per capita emissions are a critical touchpoint for global emissions equity discussions, with large developing nations such as China and India arguing that despite their growing GHG footprints, they nevertheless represent a lower per capita footprint (Heyward, 2007). To stay within the carbon budget for 1.5°C, global emissions (including at intra-national levels) must target per capita emissions of below 1tCO_2e/ca/yr by the middle of the century.

In Figure 8, the horizontal line indicates mean per capita emissions for 2005 (3.52 tCO_2e/ca/yr) as calculated in the SUT model. Mean emissions change only marginally over the period, so this line is used as a proxy for mean emissions throughout the analysis period. It is notable that the mean per capita emissions drop over this to 3.1 tCO_2e/ca/yr in 2015; however, since this is driven by stable total emissions coupled with population growth, it is not indicative of actual emissions reduction.

Per-capita emissions for most household classes rose in 2010, and then decreased in 2015, although in most cases 2015 emissions remained higher than 2005. The exception is the top two deciles (both pc_inc and pc_exp) where 2015 per capita emissions are lower than 2005.

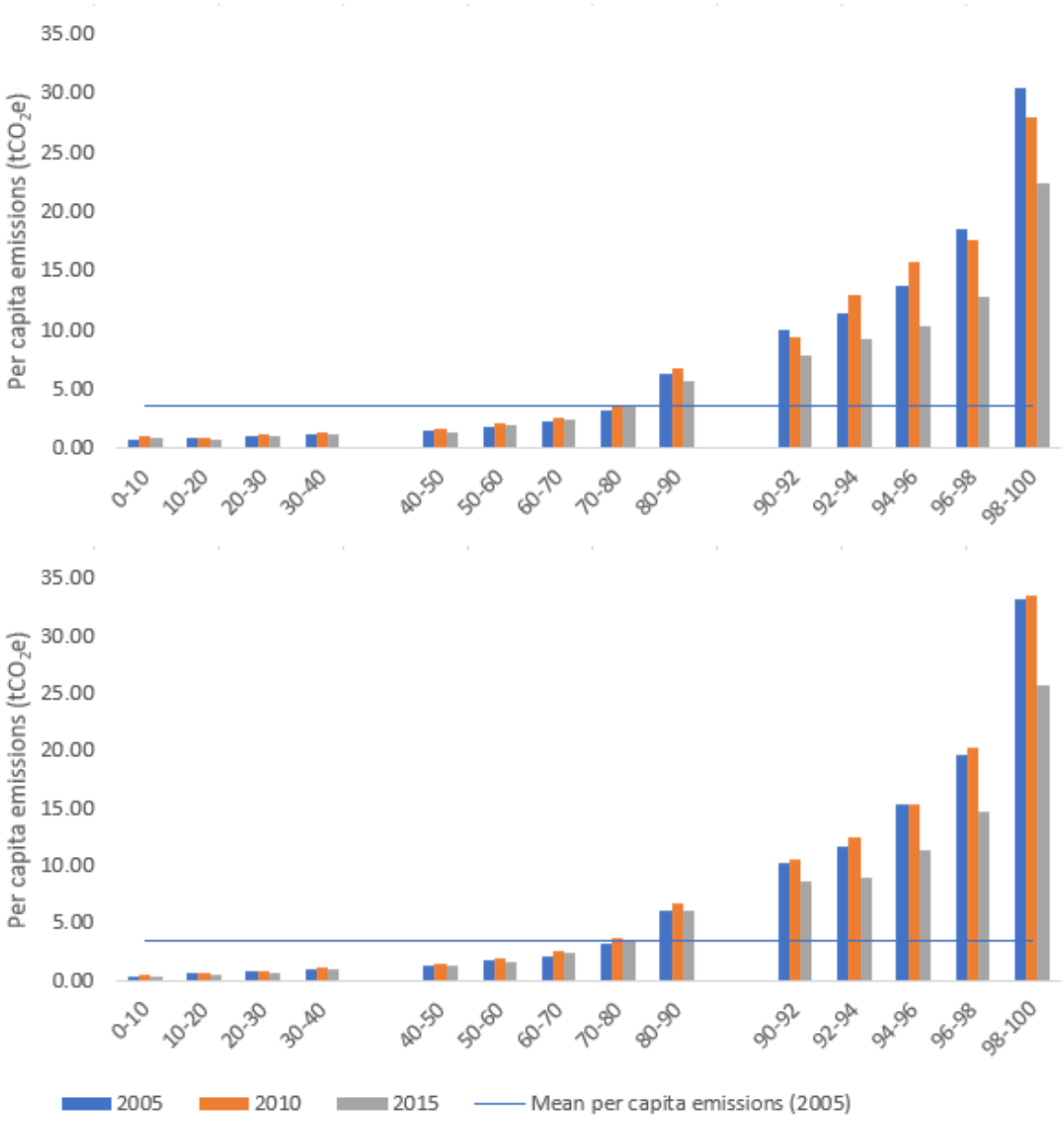

Figure 8: Annual per capita emissions (tCO_2e/ca/yr) for income (top) and expenditure (bottom) household groups. Deciles are clustered into Palma groups (lower, middle, and top). [Source: own analysis]

For both pc_inc and pc_exp, this corresponds to a growing emissions share for the middle class. For the lower Palma group (bottom 40%), the change in emissions shares illustrated above translates to a marginal gain in per capita emissions in the case of pc_inc, whilst the steady emissions share for the lower 40% of pc_exp translates to a reduction in per capita emissions.

Notably, per capita emissions for the bottom 70% of the population are below the annual mean in each of the study years, whilst emissions in the top percentile group (98-100) are a minimum of 7 times the mean in all cases.

4.7 Household climate equity assessment

As demonstrated above, whilst there are some differences in inequality measures for pc_inc and pc_exp, general trends are similar. For purposes of brevity household climate equity is thus assessed using pc_inc, since income is both a reasonable proxy for expenditure and a useful policy target because income taxes is well-reported.

4.7.1 Responsibility

Household GHG emissions are inordinately attributable to the top decile. Despite a marginal reduction in Palma ratios from 4.6 for household income groups over the period 2005 to 2015, emissions inequality remains high (3.4). The "two economies" parallel is illustrated by comparing household per capita emissions with average per capita emissions for different countries.

Household group	2005			2010			2015		
	GHG emissions (tCO_2e/ cap/ yr)	Equivalent country (tCO_2e/ cap/ yr)	Country rank	GHG emissions (tCO_2e/ cap/ yr)	Equivalent country (tCO_2e/ cap/ yr)	Country rank	GHG emissions (tCO_2e/ cap/ yr)	Equivalent country (tCO_2e/ cap/ yr)	Country rank
Top 2%	33.0	Kuwait (31.5)	2	33.3	Kuwait (30)	2	25.6	Kuwait (24.2)	3
Top 10% (Top Palma group)	17.9	Canada (17.4)	10	18.3	United States (17.7)	9	13.8	Kazakhstan (13.8)	17
Middle classes	2.9	French Polynesia (3)	122	3.2	Cuba (3.2)	121	2.9	Maldives (2.9)	121
Bottom 40% (Bottom Palma group)	0.7	Papua New Guinea (0.7)	190	0.8	Tuvalu (0.8)	190	0.6	Ghana (0.6)	196

Table 4: Per capita emissions of expenditure household groups in 2005, 2010 and 2015, indicating closest equivalent countries in terms of average national emission rates. It is notable that many of the top-ranked emitters per capita are not developed countries, but rather oil-producing states. [Source: Own analysis, with World Bank (2017) country data]

Table 4 shows the top 2% of households' emissions in 2005 approached those of Kuwait, then the world's second largest per-capita emitter. The top Palma group's emissions (18 tCO_2e/ca/yr) were equivalent to Canada (ranked 10th in total emissions globally), whilst the bottom Palma group's emissions (at 0.7 tCO_2e/ca /yr) were equivalent to Papua New Guinea, ranked 190th in global emissions. This "two economies" differentiation remained throughout the study period, with the top Palma group consistently ranked with the top emitting nations in the world, whilst the bottom Palma group equivalency dropped from 190th to 196th between 2005 and 2015. The responsibility measure did not

change significantly between 2005 and 2015; given South Africa's limited social mobility (Piraino, 2015) it is thus reasonable to assume that the 2005 measure reflects historical responsibility. Attributing intra-national fair mitigation shares by responsibility consequently puts the burden predominantly on top income deciles.

4.7.2 Capability

Household mitigation capability was assessed as per capita income in PPP-adjusted US dollars. Figure 9 below shows mean household income measured against the $7500 developmental threshold used in the CERC. Overall PPP-corrected income decreased in the period 2005 to 2015, most significantly in the top (41% reduction) and bottom (36% reduction) deciles. Nevertheless, the top Palma group's mean 2015 per capita income stands at 5.4 times the developmental threshold, with the topmost (99-100th) percentile group's income standing at 14 times the threshold value. Clearly this group has high capability for mitigation action.

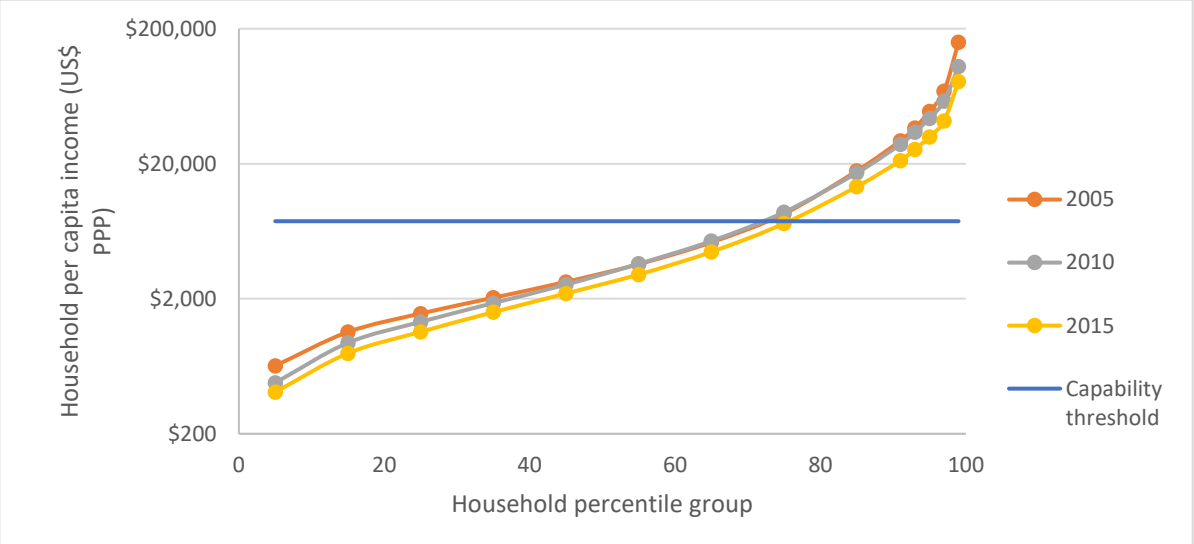

Figure 9: Household per capita income for modelled income groups measured against the CERC capability threshold of $7500 PPP/person/year. [Source: own analysis, based on data from StatsSA, OECD and CERC]

By comparison, the proportion of the population falling below the CERC developmental threshold grows from just under 72% in 2005 to over 75% in 2015, with the bottom Palma group's income dropping from an average of 17.8% to 13.1% of the threshold over the same period. The developmental threshold thus obviates three-quarters of SA's population from any mitigation burden.

4.7.3 Combined equity measure

Equity measures are calculated as per section Fair shares. The four measures detailed in Figure 10 illustrate the 2015 equity measures considering i) household responsibility derived from average group emissions; ii) household capability measured by mean decile household income, iii) household

capability after first excluding a developmental threshold; and iv) the combined equity measure that integrates household responsibility and capability above the developmental threshold. Considering responsibility alone, the bottom Palma group's share is 11.2%, the highest share for this group in all measures. The top Palma group's responsibility share is 44.1%.

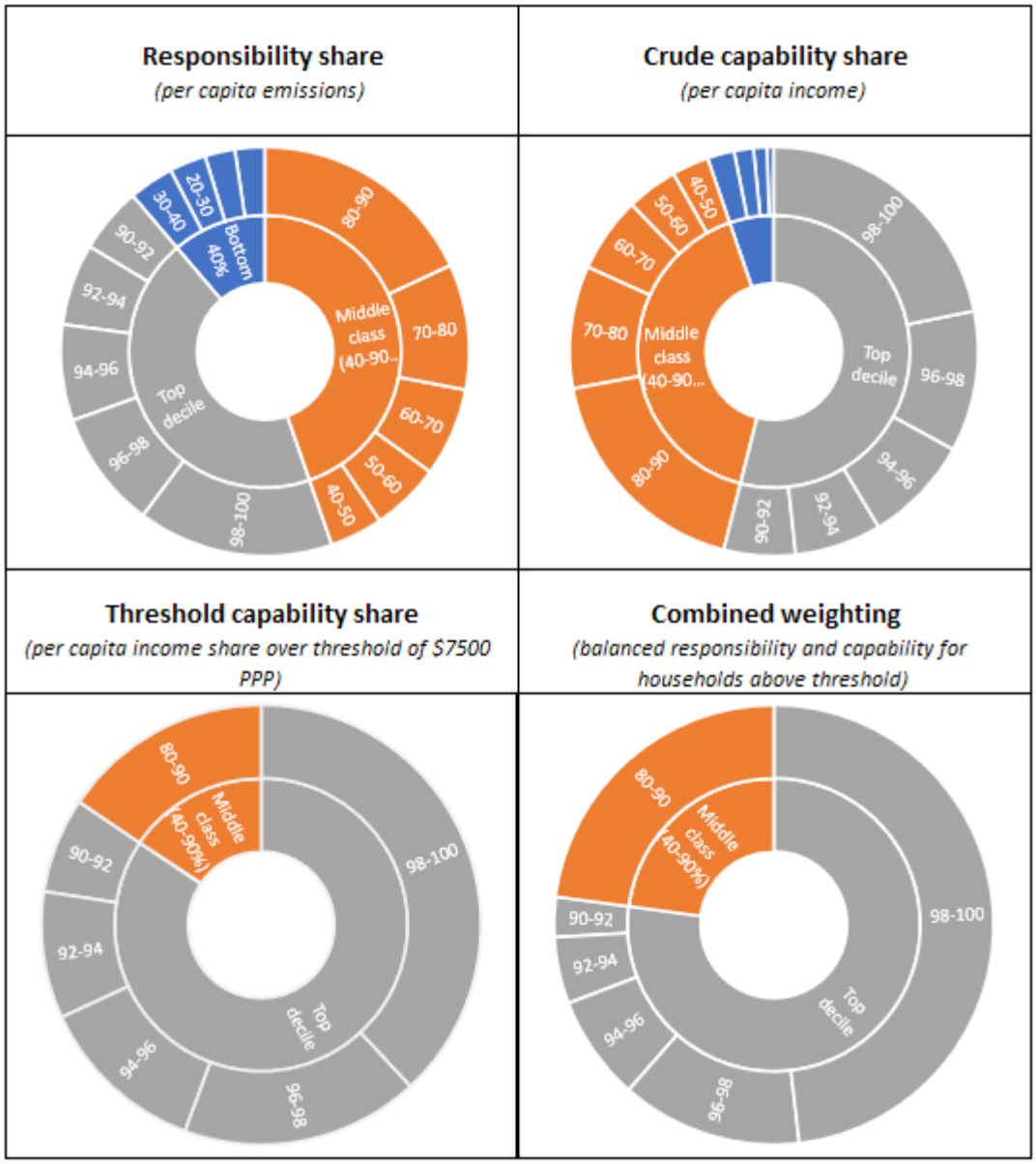

Figure 10: Evaluation of responsibility and capability shares for South African households in 2015, grouped by per capita income. Responsibility is assessed as household per capita emissions; crude capability is indicated by household per capita income; threshold capability is assessed as household share of income above the threshold value; and a combined capability and responsibility weighting is calculated by giving equal weighting to responsibility and threshold capability. Top Palma group: grey; Bottom Palma group: blue. [Source: own analysis].

For simple capability, the top Palma group's mitigation share is 52.9%, with the bottom Palma group's burden shrinking to just 5.3%. If the CERC developmental threshold is considered, top Palma household groups carry 84.4% of South Africa's capability, with the top 2% of households bearing 38.1% of the threshold capability income.

Figure 10 also illustrates a burden-sharing measure that combines historical responsibility and household capability in line with the developmental threshold outlined by the CERC. This measure indicates that **the top Palma group (decile) should bear at least 77% of the national mitigation burden, whilst the bottom 8 deciles should bear none.** This implies the need for policy mechanisms to enable the top Palma group to support mitigation in other groups.

4.8 Conclusions on results

Household shares of total national GHG emissions are highly dependent on income and expenditure. This chapter has shown that the top income decile in SA has a disproportionately large share of total emissions, and whilst measures of inequality for emissions are generally not as high as for income, they are nevertheless significant. Even within the top decile, income and expenditure effects play a significant role in the determination of household emissions, with per capita emissions nearly three times as high for the 98-100% group as for the 90-92% group.

Despite reduced per capita emissions in the upper deciles between 2005 and 2015, total household emissions remain high, and increasing middle class emissions raised the national emissions total. There was no corollary increase in the lower income deciles. In line with national income inequality, the top Palma group carries has the bulk of household mitigation capability and is responsible for a significant portion of all household GHG emissions. When considering a $7500 development threshold, fair share allocations imply that the bottom 80% of households should have no mitigation obligation.

Having considered the principles of responsibility and capability, applied to understanding patterns of inequality across households within South Africa, the thesis turns next to the implications for national policy and in relation the principles of common but differentiated rights and respective capabilities are discussed in the next chapter.

CHAPTER 5: POLICY IMPLICATIONS

This thesis aims to examine the equity dimensions of household climate change emissions in South Africa, and to discuss these considering government's national climate policy and international climate change mitigation positions as revealed through published documents. By examining South Africa's international and national policy recommendations, this chapter shows that mitigation burden-sharing should be highly progressive, with the top Palma household group carrying the bulk of SA's mitigation burden.

The previous chapter demonstrated a correlation between per capita emissions and household income or expenditure group and provided measures for household fair share allocations in line with the principle of CBDR/RC. Household emissions inequality correlates with income inequality, and when a developmental threshold is considered (Kemp-Benedict et al., 2017), mitigation burdens are allocated primarily to high income households. This chapter explores the implications of this high level of inequality by considering national positions in developmental and climate change policy and plans.

5.1 South African climate policy position

As highlighted in Chapter 2, the concept of equity and CBDR/RC is central to international climate negotiations. South Africa's own NDC to the Paris Agreement reflects the country's strong negotiating stance with respect to the necessity for an equitable approach to both mitigation and adaptation.

> *"The core principles of equity, responsibility, capability and sustainable development are the basis of South Africa's INDC[5]. Equity relates to adaptation, mitigation and all forms of investment and support."*
>
> (RSA, 2016: 10)

> *"The INDC is put forward within the context of equitable access to sustainable development and will take fully into account that equity, economic and social development and poverty eradication are the first and overriding priorities."*
>
> (RSA, 2016: 7)

The Paris Agreement's global stocktaking process is designed to encourage eventual improvement of NDCs. Whilst there is no imperative for a country's national policy to reflect international negotiating

[5] Since the intended NDC (INDC) became the NDC once there was sufficient international ratification of the Paris Agreement, the text of the NDC remained unchanged, and still refers internally to itself as the INDC.

position sregarding elements such as equity, future NDCs must consider the outcome of regular global stocktaking, and South Africa pushed for a stronger link within the Paris negotiations. It is thus informative to reflect on whether South Africa's intra-national and international positions align.

The National Development Plan (NDP), whilst not a policy document, is the essential framework and vision for the SA government's future trajectory, providing specific goals for achievement within the same timeframe as the nation's first NDC. The NDP aims to "eliminate poverty and reduce inequality by 2030 "(NPC, 2012: 24). It also recognises the need for urgent climate action, proposing it as a key developmental target.

> *"Since the threat to the world's environment and the challenge of poverty alleviation are closely intertwined, the debate should focus on ensuring that environmental policies are not framed as a choice between growth and mitigating climate change. A low-carbon future is the only realistic option..."*
>
> (NPC, 2012: 91)

The NDP also clearly articulates the necessity of a low-carbon economic transition that enables both mitigation and adaptation:

> *"The political challenge in the next two decades will be to develop policies and regulatory initiatives that prompt improved resource management and deliver substantial clean-technology industries. This will include policies that help people cope with new risks during the transition, adapting land and water management to protect livelihoods and threatened natural environments, while transforming energy systems."*
>
> (NPC, 2012: 92)

Central to the NDP is a strong focus on reducing poverty and inequality. The NDP goal of "*a capable and developmental state, able [and willing] to act to redress historical inequities*" thus strongly agrees with the country's international negotiating stance on climate.

This approach is further elaborated in the National Climate Change Response White Paper (DEA, 2012), which states that the objective of the response is to build

> *"... the climate resilience of the country, its economy and its people and manage the transition to a climate-resilient, equitable and internationally competitive lower-carbon economy and society in a manner that simultaneously addresses South Africa's over-riding national priorities for sustainable development, job*

creation, improved public and environmental health, poverty eradication, and social equality."

(DEA, 2012: 11)

There is thus a clear correspondence between SA's international climate change policy within the NDC and national planning documents such as the NDP and NCCRWP. Given this consistency in positioning, the question is whether there is strong action to enact these principles in national-level mitigation and adaptation action.

Such action should look to enhance national development opportunities and reduce national emissions, whilst following a progressive approach to shouldering the costs in line with historical and current emissions. Having considered South Africa's development plan and climate policy, this chapter now turns to an evaluation of what such equity means in terms of policy development.

5.2 Household climate equity assessment

As mentioned in Chapter 2 many measures of equity and burden-sharing responsibility exist. South Africa's international negotiating position assigns a heavy burden to nations with high historical emissions, as well as developed nations with higher capability to address climate impacts and effect a transition to a low-carbon economy. Indeed, the NDC reflects that SA assumes a heavier weighting for these equity principles, and hence a lower national obligation, than many independent assessments:

[A]nalysis by South African experts reports that a fairly apportioned overall carbon budget for South Africa for the period from 2015 to 2050 would exceed the budget implied by the upper limit of the PPD trajectory range, although other approaches to equity report a much lower number.

(RSA, 2016: 10)

SA's "two economies" structure implies obvious parallels with the disjuncture between developed and developing nations (or Annex 1 and non-Annex nations as characterized in the UNFCCC), and interpreting the principle of CBDR/RC at an intra-national level makes sense when evaluated in light of the previously described policy and planning positions.

Translating these principles to a national level, then, implies that those sectors and households most responsible for historical emissions and those with the higher capability (measured as income for individuals) should carry the burden of addressing climate change.

5.3 Addressing household fair shares

Having evaluated fair household mitigation shares, the question of supporting policy and implementation arises. Household direct emissions from fuel use fall under scope 1 (Wilson, Tyedmers & Spinney, 2013). Emissions from household electricity use fall under scope 2, and scope 3 emissions are supply chain emissions linked to household consumption; essentially embodied carbon as described under consumption-based accounting. Only scope 1 emissions (and to some extent scope 2) can be directly addressed at a household level.

Low- and high-income households' scope 1 emissions from direct energy consumption for transport, heating and cooking differ (see Decomposition of household consumption). High income households' scope 1 emissions are primarily from private transport. Some also use natural gas for heating and cooking, but most rely on electricity for these (StatsSA, 2008, 2012b). To reduce scope 1 direct emissions requires high-income households to reduce private transport usage (or shift to electric vehicles powered by renewable energy) and improve household energy efficiency.

Low-income urban households primarily use public transport, and related emissions are low even in rural areas. However, heating and cooking using biomass such as firewood and charcoal is more common in these income groups, with up to 20% of the lower Palma group using firewood as their main energy source for cooking (DoE, 2012). Since this thesis does not consider biomass use, scope 1 emissions for low income households are necessarily higher than reflected in the model. The same DoE study shows that households electrification correlates with reduced use of firewood for heating, effectively moving emissions to scope 2, with potential (but not guaranteed) emission reductions. Energy efficiency measures such as improved thermal insulation, rooftop solar water heaters and low-power lightbulbs, whilst reducing long-run household costs, are typically too expensive for such households.

Electricity emissions (scope 2) for households can be reduced through direct investment in household renewable energy[6], replacing currently largely coal-based grid electricity. With photovoltaic and energy storage prices dropping rapidly (IRENA, 2017; Tsianikas et al., 2019), the lifetime cost of installing household PV systems may soon be lower than for grid electricity. This poses a policy dilemma.

Such installations are costly, with the long-term cost savings thus only accessible for households with sufficient access to capital - incentivising high income households to save money by reducing their emissions profile. Moreover, without a proper feed-in tariff structure, these households are effectively incentivised to go off-grid. This likelihood is increased by long-term power outages due to poor maintenance and insufficient generation investment by Eskom (Baker & Phillips, 2019). Since such

[6] Other options such as combined heat and power, geothermal and district heating have limited potential in RSA.

high consumers' electricity payments subsidise the delivery of municipal services, their grid defection raises the effective price of grid power, reducing service delivery for remaining lower income households.

Given the high demand elasticity of energy consumption (Cohen, Lenzen & Schaeffer, 2005) this may cause lower-income households to increase firewood, charcoal and coal usage, with negative health implications, increasing energy poverty in such households, and offsetting total emission reductions.

These regressive effects of the "utility death spiral" entrench current inequities, even as they limit the mitigation impacts of household renewable energy. There a number of ways to address the impacts of grid defection on municipal revenue (Costello & Hemphill, 2014; Castaneda et al., 2017). Careful structuring of feed-in tariffs, smart investment in large-scale grid-linked renewables, and targeted revenue recycling to low-income households (including specific addressing of energy poverty as described by Winkler (2017)) must be undertaken in order to compensate for such effects.

The thesis has shown that higher-income households have greater responsibility and capacity to mitigate. There is demonstrably limited scope for households to directly address the respective mitigation burden, and even where high-income households undertake mitigation, it may not achieve the broader objectives because of the current municipal finance structure.

Policies requiring mitigation of scope 1 and 2 emissions by high-income households would thus be insufficient to address their mitigation burden. Scope 1 emissions from low-income households require structural and financial support from government policy, and fair shares indicate that this should be cross-subsidised by high-income households. Moreover, since the bulk of national emissions (under scope 2 and 3) cannot be addressed by households, national policies are required to raise revenue to invest in fair, just, and adequate climate mitigation action. Whether such revenues would be adequately targeted at mitigation measures is a contested question, and so such measures are still contingent on clear nationa policy for mitigation action.

5.4 Mitigation policy: status quo and options

National government has implemented some mitigation policy actions, as proposed in the NCCRWP, and in the NDC (RSA, 2016). Key legislation enacted includes monitoring and reporting of carbon dioxide emissions under the National Environment Management: Air Quality Act (RSA, 2005), and the National Carbon Tax Act (RSA, 2019b) places a nominal, if inadequate price, on GHG emissions. Additional measures under development include sectoral emissions targets, company-level emissions caps, and a draft Climate Change Act aimed at mainstreaming government climate action.

To reach the global target of 1.5°C, the world must achieve net zero emissions by 2050 (IPCC 2019). For South Africa, this implies a rapid and just transition in electricity generation from coal to renewable energy. Additional critical activities include electrification of transport, shifting freight from road to rail, and passengers to public transport. All identified mitigation options require upfront capital investment, even where they result in long-term fiscal savings (DEA, 2014). Some finance for mitigation action will be provided by multilateral facilities like the Green Climate Fund, but much must be raised internally.

Economic modelling of policy options is beyond the scope of this thesis. This chapter therefore looks briefly at literature approaches to raise and recycle revenue that align with household fair share. Revenue from internally progressive approaches can used exclusively for mitigation, whilst others require targeted recycling to ensure progressivity. This latter approach may reduce overall revenue for mitigation, although progressive mitigation approaches that reduce impacts on the poor (Winkler, 2017) could be prioritised.

5.4.1 Raising revenue

Many potential policy options exist to link raising revenue for mitigation action to household fair shares as defined in Chapter 4. Expenditure, income and wealth can all be used as indicators for progressive policy to raise revenue for mitigation action. In terms of a CBDR/RC framing, income and wealth taxes relate specifically to household capability, whilst expenditure taxes are more closely related to household responsibility for mitigation. It should be highlighted that revenue raised must also be complemented by strong fiscal commitment to mitigation action – whilst ringfencing is poor fiscal policy, failure to target revenue towards mitigation action would be insufficient to achieve the target.

It should be noted that many of the policy options discussed can drive behaviour change, such as carbon taxes, but also wealth and income taxes. However, whilst direct taxation of environmental impacts directly disincentivises the impact, almost all measures will also require mitigation strategies to enhance the avoidance of emissions and additional measures to ensure progressivity. Such policies can be complicated to implement in the milieu of South Africa's entrenched political economy, but there are no simple measures to address the dual impacts of climate and development absenting strong policy action

5.4.1.1 Income

Rather than a regressive carbon tax, Owen and Barrett (2020) propose raising income tax. SA's primary income tax threshold and rebates mean that under 10% of the population pays income tax (SARS, 2019) corresponding well to the top Palma group. Optimal tax theory literature recommends that high earners

pay rising marginal tax rates (Diamond & Saez, 2011). SA's income tax is progressive, with a top rate of 45% for income over R1.5m. However, despite lower income and wealth inequality than contemporary RSA, US top tax rates were consistently over 80% between 1940 and 1963 (IRS, 2016). These rates were not exceptional for the era, implying that there is scope for increasing progressivity for upper tax brackets. However, without strong tax enforcement and democratic reallocation structures, increased tax progressivity appears not to improve inequality in developing countries (Duncan & Sabirianova Peter, 2008; Shin, 2012), so this approach may help address mitigation without realising poverty reduction goals.

5.4.1.2 Wealth

Wealth taxes are harder to implement primarily because of the political economy, particularly in a country with high levels of inequality. SA has some measures in place to reduce wealth inequality, including estate duty and capital gains tax. Raising the marginal rates on these duties, or otherwise taxing wealth to specifically enable mitigation would align with fair shares. Leiserson (2020) proposes valuation approaches such as an annual 2% tax on all wealth, as opposed to (or in addition to) the realisation-based approach linked to capital gains or inheritance. Whilst accurately accounting wealth can be administratively challenging, such an approach could realise significant returns.

Municipal rates in South Africa are typically linked to property above a threshold value, a key indicator of wealth. Additional mitigation levies linked to property value could leverage significant additional finance for mitigation activities. However, revenue must be secured specifically for national mitigation, not for expenditure within the wards from which it is raised: localised revenue expenditure when financial and spatial segregation are linked as in South Africa is often differential, limiting progressivity (Kohler, 2015).

Financial transactions may be another viable wealth tax, since the majority of South Africa has limited access to such transactions.

5.4.1.3 Expenditure

Expenditure approaches such as value-added tax (VAT) are typically regressive because although they scale with income, the marginal impact on low income households is higher. SA's VAT rate is 15%, with a basket of zero-rated products to reduce the impact on low-income households. However, linking higher-rated VAT to revenue recycling approaches is often mooted as a component of a universal basic income grant (UBIG) discussed below, more broadly enabling progressivity in national policy (Gale, 2020),.

Environmental taxes can be hard to target at a household level since they are applied on a polluter-pays principle to disincentivise externalities. They are applied either directly to products, as with the carbon

emission tax on new vehicles, or to pollution, as with the national carbon tax, which deserves further discussion. With a sufficiently high tax rate, this Pigouvian tax incentivise low carbon and energy efficiency expenditure whilst raising revenue, making it an attractive fiscal instrument (van Heerden et al., 2016). Indeed, from an economic perspective, a carbon tax is the most attractive option, since it directly targets the market failure relating to emissions and does not require complementary national investment policy for mitigation. However, the low headline rate of R120 tCO_2e^{-1} and tax-free allowances of up to 95% (RSA, 2019b) undermine the effectiveness of the tax; this is unsurprising in light of the political economy of the minerals-industrial complex (Rennkamp, 2019).

Proposed reductions in tax-free allowances in the carbon taxes second phase (Creamer, 2019), linked to the mooted unbundling of Eskom (Ramaphosa, 2019) may enhance the effectiveness of the carbon tax in future. However, the current regulatory environment provides additional challenges to carbon tax effectiveness, including Eskom's role as sole electricity provider, and the determination of electricity generation through government mandate (DoE, 2019) which reduces opportunities for consumers to preferentially purchase renewable energy.

Energy expenditure is a larger proportion of low-income household expenses (DoE, 2012), implying a higher marginal cost for such households, and making such a tool regressive. Addressing these impacts on poorer households is discussed in the revenue recycling section below.

Given the scale of additional finance to be raised, it is likely that a combination of revenue raising measures will be required, with those targeted specifically at wealth being best aligned with fair shares, and the environmental/expenditure taxes providing the most economically simple means of targeting the market failure. However, since many of the revenue-raising options (VAT, environmental taxes, employment levies) also impact on lower income groups, fair shares also imply revenue recycling.

5.4.2 Revenue recycling

Treasury has committed to revenue-recycling measures for the carbon tax, including tax credits for renewable electricity generation, funding public transport and freight shifting initiatives, rebates for energy efficiency investments, and increased free basic electricity (FBE) to eligible citizens (National Treasury, 2018). Whilst most address mitigation needs, only FBE reduces the impact on low income households. Moreover, the challenges of FBE implementation often undermine its efficacy (Ruiters, 2009). These measures thus fail to shield households against the price effects of the carbon tax.

Winkler (2017) illustrated that targeted recycling of carbon tax revenue could reduce energy poverty through scaling up sustainable housing, subsidising rooftop PV, providing gas for cooking, and

extending electrification to unserviced households. Winkler justifies the possible emission increases from LPG or grid electrification because restricting recycling to mitigation options implies that "the rich get richer and the poor get renewables" (Annecke, 2002) – a challenge that has been raised by poor communities in South Africa. Such mitigation/development trade-offs are the core challenge for SA mitigation policy.

Additional options for revenue recycling exist, however. Winkler's proposal addresses the regressive nature of a carbon tax, whilst also capitalising on those opportunities that exist for mitigation of low-income households. Van Heerden et al. (2006) model environmental tax revenue recycling through reducing direct taxes on labour and capital, general VAT, and food VAT. Reducing VAT on food provides a triple dividend by increasing labour and GDP whilst reducing poverty. A second study shows that VAT reduction reduces the mitigation effect of the tax, whilst tax breaks for green generation increases it, illustrating the mitigation/development trade-off (van Heerden et al., 2016).

The simplest means of recycling revenue is a direct payment to individuals, possibly as a UBIG. This provides a progressive benefit, with higher marginal utility to low income households, and is administratively simple because there are no qualification criteria to be assessed. Canada's carbon tax returns 90% of revenue as tax credits to residents, with the remainder ringfenced for targeted environmental initiatives (Parliament of Canada, 2018). The Swiss carbon tax recycles one third of revenue to low-carbon building initiatives, with the remainder targeting citizens' health insurance and reducing payroll costs (FOEN, 2018).

SA has long considered the value of a UBIG (BIG Financing Reference Group, 2004), with many considering the approach as a critical means of addressing inequality (Matisonn & Seekings, 2002; Samson et al., 2002; Seekings & Matisonn, 2012). With the failure of the economy to grow employment, this may be the only way for low-income households to be provided with a means of income (Marais, 2020). Real-world experiments demonstrate that UBIG increases employment rates, improves general wellbeing (Chohan, 2017), and stimulates local economies, and has garnered interest internationally in light of job losses through robotics and low carbon transitions (Chohan, 2016).

The just transition to a low carbon economy is a key consideration for South African labour and civil society; avoiding and compensating coal sector job losses is essential (COSATU, 2011). Low-carbon electricity generation can provide more jobs per MWh than fossil fuel generation (Ferroukhi et al., 2015), but requires internalisation of the supply chain. Estimates for SA's employment opportunities from the low carbon transition range from 400,000 (Maia et al., 2011) to 1 million (Ashley et al., 2016). With necessary coal sector retrenchments and high national unemployment, a UBIG could provide a critical safety net. If funded from carbon tax, enhanced VAT or financial transaction taxes, such direct payments would help shield those with no mitigation burden whilst still raising revenue for action.

Whether direct payments qualify as a UBIG depend on the quantum, but regardless of the mechanism selected, it is clear that South Africa's commitment to fairness in the process of mitigation implies that the rich must pay more, whilst government will have to transparently and adequately ensure that the poor are not impacted, as well as target revenue at mitigation action.

5.5 Summary

This chapter demonstrates that South African international and intra-national policy supports a progressive approach to mitigating climate change. There is no limited in literature that addressing inequality either enhances or reduces overall emissions, so addressing inequality and mitigation goals in tandem may be feasible. Chapter 4 estimates households' responsibility and capability for addressing climate mitigation. Excluding households with a per capita income below the CERC development threshold, and considering both household responsibility and capability, the top Palma group (richest households) should carry most of SA's mitigation burden and cost.

The exact cost of addressing South Africa's mitigation commitment is unknown, but will certainly require substantial investment and policy consideration. To support household fair share contributions for mitigation action, revenue could be raised by targeting wealth, enhancing the effectiveness of the carbon tax or through broader measures coupled with targeted revenue recycling. Balancing the recycling of revenue to deliver mitigation goals whilst protecting low-income households is critical, because failure of the latter may increase poverty, but failure of the former is a recipe for long term disaster.

Direct universal payments may be the simplest means of ensuring revenue recycling is progressive, and it is likely necessary to realise national goals of a just energy transition. Nevertheless, the primary focus of such revenue-raising mechanisms must be on mitigating the emissions from high impact sectors, to align with NDC commitments.

CHAPTER 6: CONCLUSION

Addressing climate change is a critical global issue, requiring rapid action. However, it cannot be pursued without consideration of equity, both at an international and an intra-national level. With the most unequal society in the world, South Africa has a strong focus on poverty reduction and addressing inequality, which are highly pertinent to issues of climate mitigation and adaptation.

The aim of this thesis was to establish measures of household capability and responsibility in relation to South Africa's economic inequality, and to explore the policy implications of attributing fair household mitigation shares at an intra-national level.

Relevant literature was reviewed in chapter 2, and chapter 3 outlined the datasets and methodology used in the analysis. The results of the model and analysis were detailed in chapter4, whilst chapter 5 discussed the policy implications of the results.

6.1 Summary of findings

This thesis has explored the research question outlined in chapter 1: "Is South Africa's income inequality reflected in household GHG emissions, and what are the implications for fairly allocating the country's mitigation burden?".

Building on work from Arndt *et al.* (2013), supply-use table models were built for the years 2005, 2010 and 2015. Integrating data from the national electricity supplier Eskom, the Department of Energy, the model enables an evaluation of per-product CO_2 emissions. Household expenditure data from national surveys conducted by the national statistics agency was introduced through multiplier analysis to evaluate household emissions, including both direct emissions from fossil fuels and embodied emissions in purchased products and services. The results are summarised here.

6.1.1 Objective 1: Establish the relationship between household GHG emissions and household income and expenditure

Household CO_2 emissions scale strongly with total household income and expenditure, and high-income households are responsible for the majority of GHG emissions from household consumption; this correlation is unchanged over the period 2005 to 2015.

Households were grouped by per capita income (total household income divided by household size) and per capita expenditure. The model indicates no strong trend in household carbon intensity (measured as tCO_2e/R'000 expenditure) with increasing income or expenditure, differing from global studies which demonstrate an inverse relationship between income and emissions intensity (Golley & Meng, 2012). However, since this thesis does not include direct emissions from non-fossil fuel sources

such as biomass for cooking or heating (which tend to be higher for lower income households), it is possible that the direct emissions intensity of lower income groups is underestimated.

6.1.2 Objective 2: Evaluate the correspondence between economic inequality between households and emissions inequality

Inequality of both income and emissions was measured with the Gini index to evaluate overall inequality, as well as the Palma index to evaluate specific impacts on the outlying demographic income groups (top 10% and bottom 40%). In all cases, measures of inequality are remarkably high, with a high correspondence between household income inequality and household emissions inequality.

All measures of inequality decreased over the period 2005 to 2015. When grouped by per capita income, household emissions inequality is much lower (Gini 0.57 – 0.51; Palma 4.53 – 3.30) than income inequality (Gini 0.71 – 0.66; Palma 12.76 – 10.24). When grouped by expenditure, household emissions inequality rises (Gini 0.61 – 0.58; Palma 6.23 – 5.57), but is nevertheless lower than income inequality (Gini 0.67 – 0.60; Palma 8.74 – 5.74).

Even within the top decile there was significant inequality, with the top 2% of households claiming almost twice top decile's average income and emissions throughout the period. The per-capita emissions of these top households were equivalent to those of nations ranked in the top two globally for per capita emissions. In contrast, the per-capita emissions of the bottom Palma group (lower 4 deciles) had per capita emissions more closely aligned to those of least-developed countries. As with income, therefore, household emissions are evidence of South Africa's dual economy.

6.1.3 Objective 3: Assess whether these relationships have changed over time

Although there was some reduction in overall inequality of income and emissions over the study period, the total household CO_2 emissions did not significantly change. The minimal change in emissions inequality over the study period, coupled with historically low levels of social mobility (Leibbrandt, Ranchhod & Green, 2018), means it is reasonable to assume that historical responsibility for emissions correlates strongly to current emissions profiles.

6.1.4 Objective 4: Assess fair shares of the mitigation burden for households in different economic groupings

This thesis develops measures of household responsibility and capability to enable assessment of fair mitigation burden shares within South Africa. Holz et al (2017) proposed a "development threshold" of $7,500 (in PPP terms – marginally above the poverty line) below which people should carry no burden for mitigation. Applying this to measures of responsibility and capability provides a combined measure of fair shares in the South African context.

The combined fair shares measure indicates that, given their low responsibility and capability, there is no burden for the bottom three-quarters of households with per capita income below the developmental threshold. The top decile's fair share is 77.1% of all mitigation action, with the top 2% of households by income carrying 48.1% of the mitigation burden.

Whilst capability was more differentiated for household income groups, and responsibility more differentiated for household expenditure groups, there was little difference in overall fair share assessments for the combined measure between the groups (see Appendix 3).

6.1.5 Objective 5: Discuss the policy implications and options of such a fair share attribution

The government's international position on climate mitigation, both as articulated in climate negotiations and as formally endorsed within the NDC, places a strong focus on both historical responsibility for emissions as a driver for assignment for fair mitigation shares, and on capability for action being predicated on securing minimum developmental goals for citizens. This is reflected within the developmental agenda of national guiding policies such as the NCCRWP and NDP, which both highlight the urgency of both climate action and securing developmental gains for low income groups.

Taking seriously the interactions between development and climate policy implies that the global principles of CBDR/RC should be applied at an intra-national level. This thesis has highlighted that much of the burden for mitigation falls on those households in the top income decile, and when a developmental threshold is applied, no burden falls on the lower three quarters of the population.

To fairly apportion mitigation burdens in line with equity positions outlined in policy, government action must protect both low- and middle-income groups. Mitigating these households' direct emissions is necessary, although they lack the means to achieve it. Government must therefore enact policies designed to both reduce poverty and mitigate emissions, such as the energy poverty-reduction proposals proposed by Winkler (2017).

Transitioning the energy sector responsible for more than half of South Africa's GHG emissions is also critical and despite the long-term fiscal benefits of RE, will require large capital expenditure. Some portion of this transition will be financed through multilateral climate funds, but South Africa will nevertheless need to commit the balance. This thesis considers multiple revenue-raising options, including progressive options such as increased income tax or targeted wealth taxes, and broader taxation measures such as enhanced carbon pricing and increased VAT. No firm recommendation on the way such revenue should be raised is provided, but ensuring fair shares in line with CBDR/RC at an intra-national level requires specific policies to target the burden at the top two deciles.

For many revenue-raising measures, revenue recycling is critical to ensure that the mitigation action aligns with fair shares. Splitting revenue between targeted mitigation action and direct payments to citizens may be the simplest means to ensure progressivity. Moreover, since the transition to a low-carbon economy will necessarily entail shifts in employment, and many of the revenue-raising measures would have universal impacts, direct payments or a UBIG should be considered as a means of enabling a just transition. A UBIG would provide both an unemployment safety net and a means of enhancing the progressivity of mitigation action. There is considerable evidence that such an approach would significantly improve employment and economic function, both internationally and locally. It would also support the NDP's 2030 goal for eradicating poverty and addressing inequality.

Other options for raising and recycling revenue that could also protect fair shares may be feasible.

6.2 Concluding remarks

This thesis provides clear evidence that equitable sharing of South Africa's mitigation burden is necessary, and that the country's historical income and wealth inequality is reflected in the current burden of mitigation responsibility.

Further work in the form of integrated economic analysis of potential progressive mitigation policies fair shares is needed, and beyond the scope of this thesis. A deeper analysis linking SALDRU panel data with the national GHG inventory may also provide more insights into household responsibility for climate change.

The next ten years will be critical for both achieving the NDP's developmental goals, and climate mitigation to limit climate change to 1.5 °C. The transition required to achieve these objectives is monumental and will require a fundamental and equitable restructuring of South Africa's economy. Considering the scale of this change, government and social partners cannot afford to be timid, but must act with courage and clarity of purpose. Marais's recommendation with respect to the potential implementation of a UBIG is pertinent to the South Africa's mitigation ambition: both mitigation and poverty reduction "*have to be deployed as part of a broad transformation strategy that is led by an active state and driven by a mobilized civil society*." (Marais, 2020)

CHAPTER 7: REFERENCES

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CHAPTER 8: APPENDICES

Supplementary information is available from:

https://dx.doi.org/10.25375/uct.13661108 (Stata code)

https://dx.doi.org/10.25375/uct.13773505 (Excel SUT analysis)

Appendix 1. Carbon intensity measures

Carbon intensity measures were calculated for all products and activities, and are shown below in Table 5 and Table 6. It should be noted that industries do not have a final demand *per se*, since they are intermediate consumers, and use inputs in the manufacture of final products consumed or exported (Arndt *et al.*, 2013). As the vehicles for production, we therefore calculate the final "demand" for industries as their demand for intermediate products.

Values for 2005 differ from Arndt *et al.* (2013) for several reasons:

1. Structure of the industries varies from Arndt *et al.* study as detailed in Chapter 3 to enable comparison with the other years. This required aggregating the 171 industries to 64, changing intensities in many cases;
2. Rand values have been converted to real 2016 values to allow comparison with other years; and
3. the Eskom dataset is less nuanced, being referenced from annual reports rather than specifically secured from Eskom.

Table 5: Carbon intensity measures (tCO2e / R'000) for all industries in the SUT. Ranking is indicated by colour, ranging from dark green (least intense) to dark red (most intense). [Source: own analysis]

		Carbon intensity measure (tCO2e / R'000)		
Code	**Sector**	**2005**	**2010**	**2015**
I1	Agriculture	0.0571	0.0576	0.0578
I2	Fishing	0.0462	0.0419	0.0615
I3	Forestry	0.0241	0.0242	0.0194
I4	Mining of coal and lignite	0.0494	0.0515	0.0332
I5	Mining of gold and uranium ore	0.0394	0.0320	0.0865
I6	Mining of metal ores	0.0870	0.0841	0.0789
I7gas	Gas sector	0.1051	0.2440	0.2071
I7	Other mining and quarrying	0.0972	0.0879	0.0537
I8	Food	0.0824	0.0754	0.0432

I9	Beverages and tobacco	0.0489	0.0501	0.0312
I10	Spinning, weaving and finishing of textiles	0.1122	0.1197	0.0727
I11	Knitted, crouched fabrics, wearing apparel, fur articles	0.0653	0.0722	0.0473
I12	Tanning and dressing of leather	0.0644	0.0660	0.0382
I13	Footwear	0.0556	0.0576	0.0362
I14	Sawmilling, planing of wood, cork, straw	0.0728	0.0753	0.0452
I15	Paper	0.1797	0.1755	0.1156
I16	Publishing, printing, recorded media	0.0719	0.0675	0.0457
I17	Coke oven, petroleum refineries	0.8134	0.8976	0.7470
I18	Nuclear fuel, basic chemicals	0.1910	0.1939	0.1493
I19	Other chemical products, man-made fibres	0.1018	0.0990	0.0827
I20	Rubber	0.1065	0.1055	0.0792
I21	Plastic	0.0892	0.0926	0.0718
I22	Glass	0.1299	0.1516	0.0927
I23	Non-metallic minerals	0.1706	0.1695	0.1186
I24	Basic iron and steel, casting of metals	0.1919	0.1589	0.1630
I25	Basic precious and non-ferrous metals	0.1517	0.1366	0.1346
I26	Fabricated metal products	0.0890	0.0761	0.0658
I27	Machinery and equipment	0.0666	0.0557	0.0436
I28	Electrical machinery and apparatus	0.0738	0.0697	0.0662
I29	Radio, television, communication equipment and apparatus	0.0382	0.0393	0.0283
I30	Medical, precision, optical instruments, watches and clocks	0.0497	0.0509	0.0300
I31	Motor vehicles, trailers, parts	0.0641	0.0621	0.0423
I32	Other transport equipment	0.0678	0.0662	0.0340
I33	Furniture	0.0695	0.0740	0.0446
I34	Manufacturing n.e.c, recycling	0.0680	0.0651	0.0449
I35	Electricity, gas, steam and hot water supply	1.6564	1.3184	0.9260
I36	Collection, purification and distribution of water	0.1873	0.1532	0.0672
I37	Construction	0.0746	0.0680	0.0530
I38	Wholesale trade, commission trade	0.0510	0.0489	0.0337
I39	Retail trade	0.0507	0.0503	0.0290
I40	Sale, maintenance, repair of motor vehicles	0.0480	0.0446	0.0388
I41	Hotels and restaurants	0.0536	0.0487	0.0246
I42	Land transport, transport via pipelines	0.0798	0.0733	0.0542
I43	Water transport	0.1167	0.0884	0.0833
I44	Air transport	0.1101	0.0938	0.0809
I45	Auxiliary transport	0.0464	0.0492	0.0571
I46	Post and telecommunication	0.0750	0.0868	0.0266
I47	Financial intermediation	0.0153	0.0134	0.0099
I48	Insurance and pension funding	0.0109	0.0088	0.0070
I49	Activities to financial intermediation	0.0025	0.0021	0.0022
I50	Real estate activities	0.0659	0.0648	0.0530
I51	Renting of machinery and equipment	0.0640	0.0602	0.0467
I52	Computer and related activities	0.0992	0.0884	0.0792
I53	Research and experimental development	0.0807	0.0754	0.0344
I54	Other business activities	0.0828	0.0801	0.0698

I55	Government	0.0314	0.0347	0.0153
I56	Education	0.0631	0.0569	0.0364
I57	Health and social work	0.0555	0.0507	0.0343
I58	Sewerage and refuse disposal	0.0617	0.0585	0.0290
I59	Activities of membership organisations	0.0705	0.0668	0.0337
I60	Recreational, cultural and sporting activities	0.0799	0.0742	0.0425
I61	Other activities	0.0840	0.0820	0.0433
I62	Non-observed, informal, non-profit, households,	0.0328	0.0308	0.0217

Table 6: Carbon intensity measures (tCO2e / R'000) for all products in the SUT. Rank is indicated by colour, ranging from dark green (least intense) to dark red (most intense). [Source: own analysis]

		Carbon intensity measure (tCO2e / R'000)		
Code	**Sector**	**2005**	**2010**	**2015**
P1	Agriculture	0.0465	0.0484	0.0472
P2	Live animal	0.0451	0.0459	0.0425
P3	Forestry	0.0428	0.0400	0.0522
P4	Fishing	0.0169	0.0180	0.0145
P5	Coal and lignite	4.7747	3.3990	3.3202
P6	Metal ores	0.0733	0.0700	0.0790
P7	Other minerals	0.0749	0.1030	0.0390
P7gas	Natural gas	0.4555	0.5160	0.8528
P7oil	Crude oil	0.7014	0.6017	0.6153
P8	Electricity and gas	1.0583	0.8783	0.5027
P9	Natural water	0.1798	0.1555	0.0672
P10	Meat	0.0544	0.0550	0.0295
P11	Fish	0.0560	0.0535	0.0266
P12	Vegetables	0.0566	0.0530	0.0237
P13	Fruit and nuts	0.0563	0.0532	0.0323
P14	Oils and fats	0.0438	0.0345	0.0141
P15	Dairy products	0.0625	0.0569	0.0255
P16	Grain mill products	0.0654	0.0609	0.0260
P17	Starches products	0.0717	0.0632	0.0334
P18	Animal feeding	0.0551	0.0499	0.0211
P19	Bakery products	0.0556	0.0513	0.0308
P20	Sugar	0.0611	0.0544	0.0249
P21	Confectionary products	0.0386	0.0367	0.0243
P22	Pasta products	0.0591	0.0509	0.0199
P23	Food n.e.c.	0.0476	0.0455	0.0231
P24	Alcohol, beverages	0.0284	0.0266	0.0118
P25	Soft drinks	0.0353	0.0347	0.0212
P26	Tobacco products	0.0193	0.0185	0.0087
P27	Textile fabrics	0.0696	0.0734	0.0451

P28	Made-up textile, articles	0.0500	0.0462	0.0215
P29	Carpets	0.0540	0.0534	0.0329
P30	Textile n.e.c.	0.0546	0.0537	0.0322
P31	Knitting fabrics	0.0523	0.0549	0.0114
P32	Wearing apparel	0.0311	0.0303	0.0199
P33	Leather products	0.0413	0.0390	0.0156
P34	Footwear	0.0221	0.0233	0.0106
P35	Wood products	0.0563	0.0551	0.0321
P36	Paper products	0.1262	0.1095	0.0673
P37	Printing	0.0510	0.0457	0.0292
P38	Petroleum products	0.3331	0.2800	0.2645
P39	Basic chemicals	0.1383	0.1325	0.1288
P40	Fertilizers, pesticides	0.1165	0.1019	0.0507
P41	Paint, related products	0.1017	0.0912	0.0464
P42	Pharmaceutical products	0.0613	0.0559	0.0330
P43	Soap, cleaning, perfume	0.0770	0.0707	0.0474
P44	Chemical products, n.e.c.	0.0864	0.0786	0.0706
P45	Rubber tyres	0.0659	0.0583	0.0377
P46	Other rubber products	0.0660	0.0662	0.0357
P47	Plastic products	0.0607	0.0502	0.0339
P48	Glass products	0.0835	0.0906	0.0492
P49	Non-structural ceramic	0.0933	0.0990	0.0479
P50	Structure non-refractory clay	0.1047	0.1047	0.0628
P51	Plaster, cement	0.1187	0.1146	0.0466
P52	Articles of concrete	0.1044	0.0944	0.0709
P53	Non-metallic products n.e.c.	0.1258	0.1072	0.1136
P54	Furniture	0.0491	0.0495	0.0233
P55	Jewellery	0.0410	0.0355	0.0204
P56	Manufactured products n.e.c.	0.0146	0.0130	0.0152
P57	Wastes, scraps	0.0638	0.0512	0.0350
P58	Iron, steel products	0.1401	0.1014	0.1070
P59	Non-ferrous metals	0.1089	0.0633	0.0787
P60	Structural metal products	0.0714	0.0497	0.0397
P61	Tanks, reservoirs	0.0736	0.0459	0.0335
P62	Other fabricated metal	0.0680	0.0510	0.0332
P63	Engines, turbines	0.0262	0.0165	0.0042
P64	Pumps, compressors	0.0304	0.0223	0.0167
P65	Bearings, gears	0.0269	0.0229	0.0124
P66	Lifting equipment	0.0305	0.0225	0.0129
P67	General machinery	0.0273	0.0232	0.0179
P68	Special machinery	0.0299	0.0215	0.0187
P69	Domestic appliances	0.0257	0.0216	0.0138
P70	Office machinery	0.0083	0.0066	0.0087
P71	Electrical machinery	0.0464	0.0394	0.0257
P72	Radio, television	0.0171	0.0160	0.0100
P73	Medical appliances	0.0129	0.0131	0.0059
P74	Motor vehicles, parts	0.0335	0.0288	0.0166
P75	Ships and boats	0.0490	0.0221	0.0069

P76	Railway and trams	0.0500	0.0391	0.0154
P77	Aircrafts	0.0082	0.0097	0.0204
P78	Other transport equipment	0.0228	0.0189	0.0072
P79	Construction	0.0724	0.0700	0.0528
P80	Construction services	0.0570	0.0624	0.0407
P81	Trade services	0.3519	0.3089	1.9137
P82	Accommodation	0.0357	0.0367	0.0192
P83	Catering services	0.0405	0.0400	0.0170
P84	Passenger transport	0.0742	0.0710	0.0519
P85	Freight transport	0.1402	0.1004	0.1357
P86	Supporting transport services	0.0449	0.0439	0.0570
P87	Postal, courier services	0.0703	0.0722	0.0235
P88	Electricity distribution	1.6518	1.3412	0.8840
P89	Water distribution	0.1770	0.1488	0.0627
P90	Financial services	0.0196	0.0172	0.0121
P91	Insurance, pension	0.0103	0.0083	0.0065
P92	Other financial services	0.0024	0.0021	0.0033
P93	Real estate services	0.0619	0.0629	0.0511
P94	Leasing, Rental services	0.0710	0.0677	0.0542
P95	Research, development	0.0680	0.0694	0.0511
P96	Legal, accounting	0.0522	0.0650	0.0423
P97	Other business services	0.1188	0.1135	0.0617
P98	Telecommunications	0.0711	0.0807	0.0224
P99	Support services	0.1803	0.1773	0.0551
P100	Manufactured services n.e.c.	0.0582	0.0557	0.0515
P101	Public administration	0.0313	0.0353	0.0150
P102	Education services	0.0594	0.0576	0.0363
P103	Health, social services	0.0529	0.0484	0.0303
P104	Other services n.e.c.	0.0576	0.0581	0.0229

Appendix 2. Decomposition of household consumption

Household consumption differs between household classes, which affects the total carbon intensity measures. The figures below demonstrate for each household income and expenditure class both the proportional contribution of different product group to the total CIM, and the proportional household expenditure on each product group as a fraction of mean expenditure for each household class. Since there are many individual products, products are aggregated into groups of related products, enabling better differentiation in the figures.

In each of Figure 11, Figure 12 and Figure 13 below, the top row demonstrates respective contributions of each aggregate class to the average household CIM for each household class as well as for average household CIM. The bottom row shows proportional household expenditure on each aggregate product group as a fraction of mean expenditure for each household class. Households are aggregated by pc_inc on the left, and pc_exp on the right.

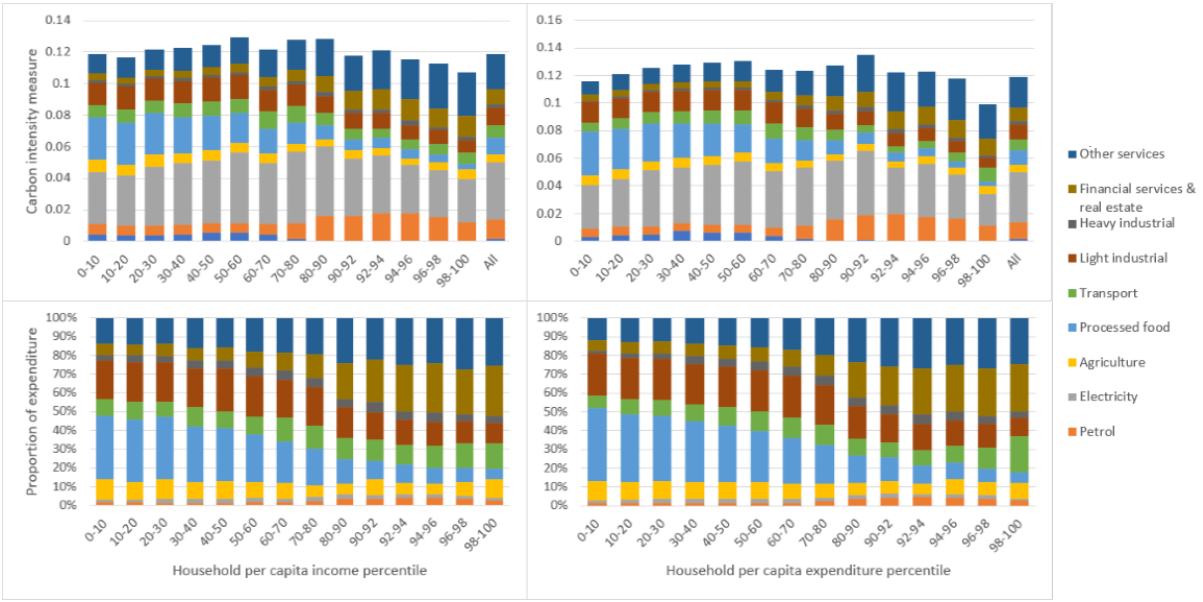

Figure 11: Decomposition of carbon intensity and expenditure product groups for household income and expenditure class, 2005. [Source: own analysis]

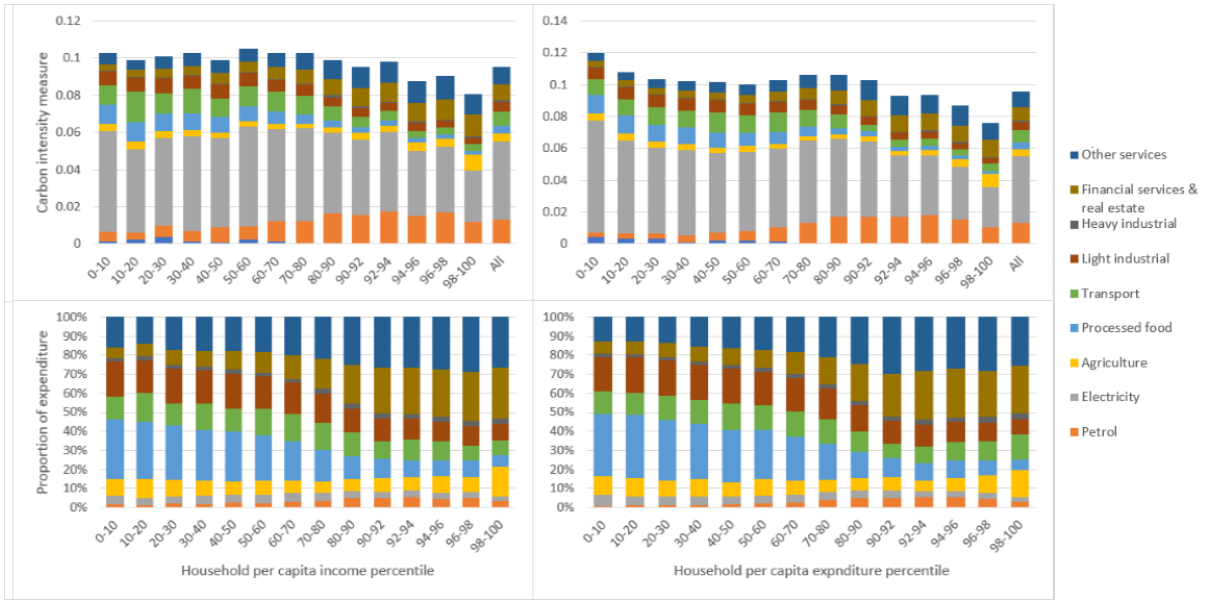

Figure 12: Decomposition of carbon intensity and expenditure product groups for household income and expenditure class, 2010. [Source: own analysis]

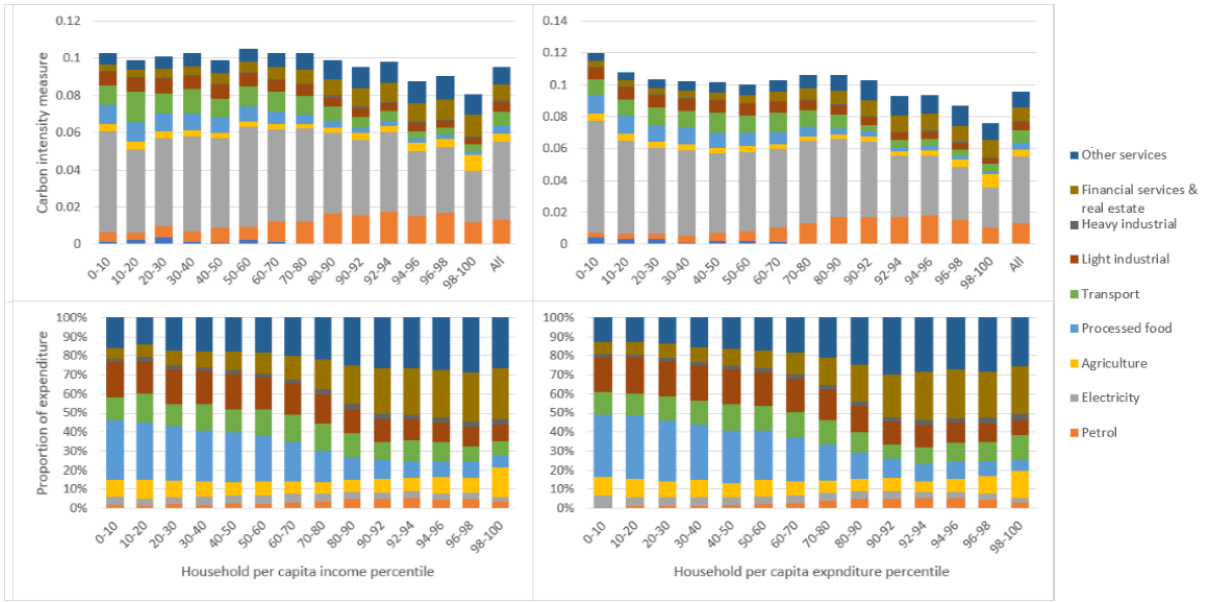

Figure 13: Decomposition of carbon intensity and expenditure product groups for household income and expenditure class, 2015. [Source: own analysis]

Appendix 3. Household fair share measures

Although this thesis presents data exclusively for the household income groups for purposes of brevity, the 2015 household equity measures were assessed for both pc_inc and pc_exp, as below.

A3.1 Income groups (pc_inc)

Household income percentile	Responsibility share (R_H)	Crude capability share (C_H)	Threshold capability share (CT_H)	Combined equity share (FS_H)
0-10	2.4%	0.5%	0.0%	0.0%
10-20	2.4%	1.1%	0.0%	0.0%
20-30	2.9%	1.5%	0.0%	0.0%
30-40	3.6%	2.1%	0.0%	0.0%
40-50	4.2%	2.9%	0.0%	0.0%
50-60	5.5%	4.1%	0.0%	0.0%
60-70	7.0%	6.0%	0.0%	0.0%
70-80	9.9%	9.7%	0.0%	0.0%
80-90	18.1%	18.1%	15.6%	22.9%
90-92	5.2%	5.7%	7.0%	3.0%
92-94	6.4%	6.9%	9.3%	4.9%
94-96	7.6%	8.5%	12.5%	7.7%
96-98	9.3%	11.1%	17.5%	13.3%
98-100	15.5%	21.8%	38.1%	48.1%

Table 7: Fair shares per household income decile (pc_inc) for each of the four measures assessed. Palma groups are coloured in blue (bottom 40%), orange (middle class) and grey (top decile). [Source: own analysis]

These values are presented diagrammatically in Figure 10 in Chapter above.

A3.2 Expenditure groups (pc_exp)

Household income percentile	Responsibility share (R_H)	Crude capability share (C_H)	Threshold capability share (CT_H)	Combined equity share (FS_H)
0-10	1.0%	1.3%	0.0%	0.0%
10-20	1.7%	1.9%	0.0%	0.0%
20-30	2.3%	2.2%	0.0%	0.0%
30-40	3.0%	2.9%	0.0%	0.0%
40-50	3.8%	3.4%	0.0%	0.0%
50-60	5.0%	4.7%	0.0%	0.0%
60-70	6.8%	6.6%	0.0%	0.0%
70-80	10.1%	10.3%	0.5%	0.4%
80-90	18.1%	19.3%	19.8%	27.0%
90-92	5.6%	5.4%	7.2%	3.1%
92-94	6.3%	6.9%	10.5%	5.0%
94-96	8.0%	7.8%	12.3%	7.5%
96-98	10.5%	10.1%	17.3%	13.7%
98-100	17.8%	17.2%	32.4%	43.4%

Table 8: Fair shares per household expenditure decile (pc_exp) for each of the four measures assessed. Palma groups are coloured in blue (bottom 40%), orange (middle class) and grey (top decile). [Source: own analysis]

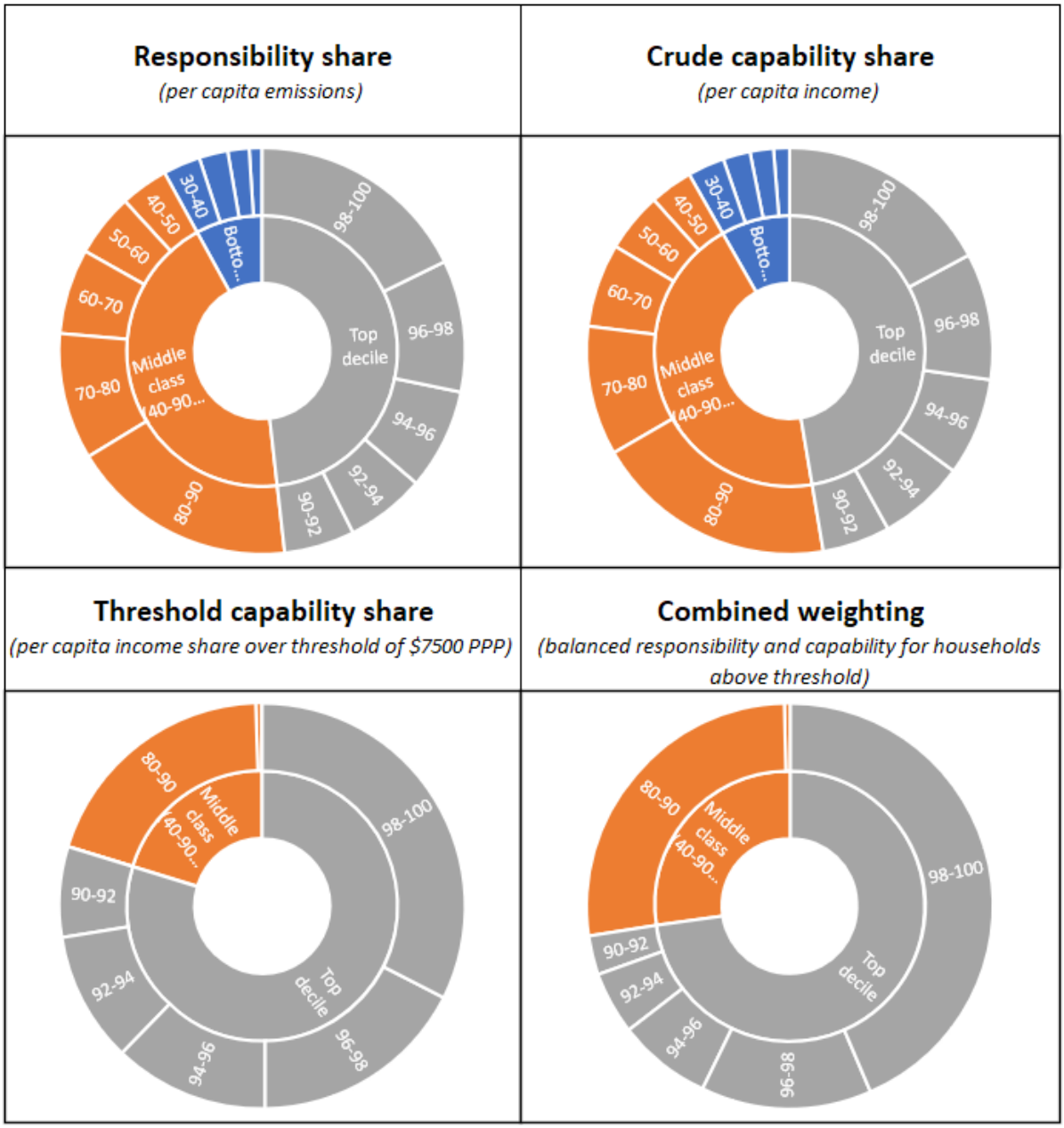

Figure 14: Evaluation of responsibility and capability shares for South African households in 2015, grouped by per capita expenditure (pc_exp). Responsibility is assessed on the basis of household per capita emissions; crude capability for mitigation is indicated by household per capita income; threshold capability is assessed as household share of income above the threshold value; and a combined capability and responsibility weighting is calculated by giving equal weighting to responsibility and threshold capability. Top Palma group: grey; Bottom Palma group: blue. [Source: own analysis]

Appendix 4. Annotated Stata code

For each of the IES/LCS datasets, some preliminary preparation was required to classify households by income and expenditure group, applying weightings and classifying all COICOP expenditures into relevant SUT groups.

Stat code used for processing data for each of the IES and LCS datasets can be viewed on UCT ZivaHub: https://dx.doi.org/10.25375/uct.13661108.

An example of annotated STATA code for processing the 2005/2006 IES data is provided. The output provides aggregate expenditure per SUT for each of the pc_inc and pc_exp household classes. This data was then used to align expenditures with the total SUT expenditures.

All household and individual weightings were calculated by StatsSA for the full dataset, and were provided with together with the curated datasets. For details on the methodology for calculation of these weightings (including potential sampling bias, over/under-sampling for given demographics, non-response errors, and adjustments for enumeration areas which had fewer than 25 households (which were excluded from sampling), please read the relevant metadata for the respective datasets (StatsSA, 2012c)

```
**** Household Income/expenditure (2005/2006) Do File (Stata analysis)
*****************************
/* James Reeler
 2005/2006 Household income and Expenditure Survey
 21,144 households (UQNO)
 84,978 people
 Population estimates:
 12,457,581 households
 47,390,900 individuals
 */

*************************************************************
      set more off
* set working directory
      global wf "C:\Users\Jay\Documents\Cloud Data\OneDrive\ACDI
2018\Thesis\Data\IES\IES_2005\Analysis"
      cd "$wf"
* set up logging
      cap log close
      log using IES2005_6,replace

*=================================================================================
* GLOBALS FOR DATA FILES AND VERSION SUFFIXES
* Type of data being used, Anon or Secure
      global TYPE "Anon"
* Inflation value for calculating real expenditure/income. Derived from CPI data
http://www.statssa.gov.za/?page_id=1854&PPN=P0141&SCH=7617
* IES 2005 prices are in March 2006 prices, here inflated/deflated to Dec 2016
      global inflation_correction 0.521
```

```
	global year 2005
```

```
* Protect primary data by working with copies *

* rename data files for simplicity
	use ..\Data\Original\ies_2005-2006_house_info_v2.1.dta, clear
	save ..\Data\Houseinfo, replace

	use ..\Data\Original\ies_2005-2006_person_info_v2.1.dta, clear
	save ..\Data\Personinfo, replace

	use ..\Data\Original\ies_2005-2006_total_v2.1.dta, clear
	save ..\Data\totalIES, replace

** Individual income is not used because the dataset already aggregates individual
income and in kind income at a household level


*creates a numbered id for each household (1,2,3,etc.)
	use ..\Data\Houseinfo, clear
	gen id = _n
	label var id "Household ID"
	keep uqno weight id
	sort uqno weight
	save 0id, replace

* replace the uqno in all datasets with the household id created above
* the variable is still called uqno
	use ..\Data\Personinfo, clear
	sort uqno
	merge m:1 uqno using 0id
	tab _m
	drop _m
	order id
	drop uqno
	rename id UQNO
	rename weight p_weight
	rename personno PERSONNO
	save ..\Newdata\Personinfo, replace

/*
IES/LCS datasets have income calculated using both direct and in-kind
contributions. They are reported from diaries and interviews, and annualised over
a whole year.
*/
	use ..\Data\Houseinfo, clear
	sort uqno weight
	merge 1:1 uqno weight using 0id
	tab _m
	drop _m
	order id
	drop uqno
	rename id UQNO
	* Calculate real value for income (adjusted to Dec 2016 Rands) *
	rename inkindincome income_inkind
	replace income_inkind = income_inkind / $inflation_correction
	rename weight hh_wgt
	rename hsize hhsize
	save ..\Newdata\Houseinfo, replace
```

```
	keep UQNO hhsize hh_wgt
	save 1hhsize, replace

	use ..\Data\totalIES, clear
	sort uqno weight
	merge m:1 uqno weight using 0id
	tab _m
	drop _m
	order id
	drop uqno
	rename id UQNO
	* Calculate real value for annualized expenditure value (adjusted to Dec
2016 Rands) *
	gen coicop_exp_adj = valueannualized / $inflation_correction
	label var coicop_exp_adj "Expenditure on coicop, adjusted to Dec 2016
rands"
	rename weight hh_wgt
	save ..\Newdata\totalIES, replace

* Income and expenditure ---------------------
* import SUT definitions. This is a text file containing correlations between
individual COICOPs and relevant SU categories, prepared using the IES metadata and
the SU classifications from StatsSA.
* Non-expenditure SUs are not considered here.
	import delimited ..\..\Coicop_sut.csv, clear
	sort coicop
	save 0coicop, replace

* Use COICOP/SUT equivalencies to allocate all COICOPs recorded in household
expenditures to the relevant SU class.
* Expenditure for each SUT is aggregated per household.
	use ..\Newdata\totalIES, clear
	sort coicop
	merge m:1 coicop using 0coicop
	tab _m
	drop if _m ~= 3
	drop _m
	drop if sut > 106
	collapse (sum) coicop_exp_adj, by (sut UQNO)
	rename coicop_exp_adj sut_exp_adj
	label var sut_exp_adj "Expenditure per SUT"
	sort UQNO sut
	sort sut

	save 2workfile, replace
*_____________________________________________________________________
	* new dataset to assign people to households and allocate
expenditure/income to people.

	use ..\newdata\Personinfo, clear
    sort UQNO
	gen id_p = _n
	keep UQNO PERSONNO p_weight id_p
	sort UQNO p_weight PERSONNO id_p
	save 0id_p, replace

	* integrate individuals and individual weightings into the workfile
```

```
use 0id_p, clear
sort UQNO
merge m:m UQNO using 2workfile
tab _m
drop if _m ~= 3
drop _m
save 2workfile,replace
```

```
/*-------------------------Household classification by per capita income---------
----------
Classification of households by income allows determination of household
CAPABILITY. However, emissions for the households are still calculated using
household expenditure values, since this corresponds to emissions.
Direct income and income in kind per household are provided in the IES/LCS
datasets.
Households are classified using in-kind income, and taxes and debts are not
considered.
Household income is evaluated on a per capita basis, to compensate for household
size and multiple income effects.
The IES/LCS provides weightings for each household and individuals with income.
Weightings consider the stratified survey approach, and compensate for over/under-
represenation, non-response errors and exclusions for small evaluation areas, on
the basis of the 2001 census.
Individual weightings are applied here where they differ from the calculated
household weighting.
*/
```

```
use ..\Newdata\Houseinfo, clear
collapse (sum) income_inkind, by (UQNO)
rename income_inkind hh_tot_income
save 1temp, replace
```

```
use ..\newdata\Houseinfo, clear
sort UQNO
merge 1:1 UQNO using 1temp
tab _m
drop if _m ~= 3
drop _m
* per capita income for each household
gen pcinc = hh_tot_income  / hhsize
label var pcinc "Per capita income for household"
sort UQNO
save 2workfile_1, replace
* include individuals and personal weightings
use 0id_p, clear
sort UQNO
merge m:1 UQNO using 2workfile_1
tab _m
drop if _m ~= 3
drop _m
save 2workfile_2,replace
*Classify households according to weighted total income (including in kind
income).
use 2workfile_2, clear
xtile decile=pcinc [pw=p_weight], nquantiles(10)
xtile top=pcinc if decile == 10 [pw=p_weight], nquantiles(5)
```

```
        recode top (.=0)
        replace top = top -1 if top ~= 0
        gen hhdclass = decile + top
        *define 14 household classes, correspondingg to 9 deciles and a tenth
decile split into five 2% groupings
        label define hhdclass 1 "0-10" 2 "11-20" 3 "21-30" 4 "31-40" 5 "41-50" 6
"51-60" 7 "61-70" 8 "71-80" 9 "81-90" 10 "91-92" 11 "93-94" 12 "95-96" 13 "97-98"
14 "99-100"
        label val hhdclass hhdclass
        label var hhdclass "Income decile for household"

        sort UQNO
        save 1hhdclass_p, replace

        erase 1temp.dta

        * Generate household class size variables. First nine classes are 10% of
the population, whilst the last five are each 2%
        use 1hhdclass_p, clear
        gen hhdclass_size = hhdclass
        egen personcount = sum(p_weight)
        replace hhdclass_size = personcount/50 if hhdclass>9
        replace hhdclass_size = personcount/10 if hhdclass<10
        label var hhdclass_size "Number of households in class"
        keep hhdclass hhdclass_size hhsize
        collapse(first) hhdclass_size, by (hhdclass)
        merge 1:m hhdclass using 1hhdclass_p
        tab _m
        drop if _m ~= 3
        drop _m
        keep id_p UQNO p_weight hhdclass hhdclass_size hhsize hh_wgt
        sort id_p
        save 1hhdclass_p, replace

/*--------------------------Household classification BY EXPENDITURE-------------
-----
Classification of households by expenditure allows evaluation of the deciles most
and least responsible for overall emissions, driven by average percentile
household emissions.
As with income classification, weightings calculated in the IES are used to ensure
that the estimates are representative of the real population
*/
        use 2workfile, clear
        collapse (sum) sut_exp_adj, by(UQNO)
        save 1temp, replace

        use ..\newdata\Houseinfo, clear
        sort UQNO
        merge 1:m UQNO using 1temp
        tab _m
        drop if _m ~= 3
        drop _m
*per capita expenditure for each household
        gen pcexp = sut_exp_adj / hhsize
        sort UQNO
        save 2workfile_3, replace

        use 0id_p, clear
        sort UQNO
```

```
	merge m:m UQNO using 2workfile_3
	tab _m
	drop if _m ~= 3
	drop _m
	save 2workfile_4,replace

	use 2workfile_4, clear
	xtile decile=pcexp [pw=p_weight], nquantiles(10)
	xtile top=pcexp if decile == 10 [pw=p_weight], nquantiles(5)
	recode top (.=0)
	replace top = top -1 if top ~= 0
	gen hhdclass = decile + top
	label define hhdclass 1 "hhd0" 2 "hhd1" 3 "hhd2" 4 "hhd3" 5 "hhd4" 6 "hhd5"
7 "hhd6" 8 "hhd7" 9 "hhd8" 10 "hhd91" 11 "hhd92" 12 "hhd93" 13 "hhd94" 14 "hhd95"
	label val hhdclass hhdclass

	keep id_p UQNO hhdclass p_weight hhsize hh_wgt
	sort id_p
	save 1hhdclass_pexp, replace


		* generate household class size variables
	use 1hhdclass_pexp, clear
	gen hhdclass_size = hhdclass
	egen personcount = sum(p_weight)
	replace hhdclass_size = personcount/50 if hhdclass>9
	replace hhdclass_size = personcount/10 if hhdclass<10
	label var hhdclass_size "Number of households in class"
	keep hhdclass hhdclass_size hhsize
	collapse(first) hhdclass_size, by (hhdclass)
	merge 1:m hhdclass using 1hhdclass_pexp
	tab _m
	drop if _m ~= 3
	drop _m
	keep id_p UQNO p_weight hhdclass hhdclass_size hhsize hh_wgt
	sort id_p
	save 1hhdclass_pexp, replace


*****************************
* Table 1: Total household expenditure by income class (Rm)
	use 2workfile, clear
	keep sut id_p sut_exp_adj p_weight
	sort id_p
	merge m:1 id_p using 1hhdclass_p
	tab _m
	drop if _m ~= 3
	drop _m

	** Convert to total expenditure in Rm, to correlate to SUT units.
	replace sut_exp_adj = (sut_exp_adj)/1000000
	* Annualised expenditure for each SUT is aggregate per household class,
after applying relevant weighting
	collapse (sum) sut_exp_adj [iw=hh_wgt], by (sut hhdclass)
	label var sut_exp_adj "Total expenditure (Rm weighted & annualized) for
hhdclass"
	save 2hhdsutinc, replace

	use 2hhdsutinc, clear
```

```
        reshape wide sut_exp_adj, i(sut) j(hhdclass)
        renpfix sut_exp_adj hhd
        * apply labels for the SUT classes
        label define sut 1 "P1" 2 "P2" 3 "P3" 4 "P4" 5 "P5" 6 "P6" 7 "P7" 8 "P7gas"
9 "P7oil" 10 "P8" 11 "P9" 12 "P10" 13 "P11" 14 "P12" 15 "P13" 16 "P14" 17 "P15" 18
"P16" 19 "P17" 20 "P18" 21 "P19" 22 "P20" 23 "P21" 24 "P22" 25 "P23" 26 "P24" 27
"P25" 28 "P26" 29 "P27" 30 "P28" 31 "P29" 32 "P30" 33 "P31" 34 "P32" 35 "P33" 36
"P34" 37 "P35" 38 "P36" 39 "P37" 40 "P38" 41 "P39" 42 "P40" 43 "P41" 44 "P42" 45
"P43" 46 "P44" 47 "P45" 48 "P46" 49 "P47" 50 "P48" 51 "P49" 52 "P50" 53 "P51" 54
"P52" 55 "P53" 56 "P54" 57 "P55" 58 "P56" 59 "P57" 60 "P58" 61 "P59" 62 "P60" 63
"P61" 64 "P62" 65 "P63" 66 "P64" 67 "P65" 68 "P66" 69 "P67" 70 "P68" 71 "P69" 72
"P70" 73 "P71" 74 "P72" 75 "P73" 76 "P74" 77 "P75" 78 "P76" 79 "P77" 80 "P78" 81
"P79" 82 "P80" 83 "P81" 84 "P82" 85 "P83" 86 "P84" 87 "P85" 88 "P86" 89 "P87" 90
"P88" 91 "P89" 92 "P90" 93 "P91" 94 "P92" 95 "P93" 96 "P94" 97 "P95" 98 "P96" 99
"P97" 100 "P98" 101 "P99" 102 "P100" 103 "P101" 104 "P102" 105 "P103" 106 "P104"

        label values sut sut
        sort sut
        save ..\Output\hhdincSUTuse, replace
        * export to excel file
        export excel using "..\Output\\$year.xlsx", firstrow(varlabels)
sheetreplace sheet("1. SUT(inc)")

* Table 2: Total household expenditure by expenditure class (Rm)
        use 2workfile, clear
        *keep sut id_p sut_exp_adj p_weight hh_wgt
        sort id_p
        merge m:1 id_p using 1hhdclass_pexp
        tab _m
        drop if _m ~= 3
        drop _m

        * Convert to total expenditure in Rm, to correlate to SUT units.
        replace sut_exp_adj = (sut_exp_adj)/1000000
        * Annualised expenditure for each SUT is aggregate per household class,
after applying relevant weighting
        collapse (sum) sut_exp_adj [iw=hh_wgt], by (sut hhdclass)
        label var sut_exp_adj "Total expenditure (Rm weighted & annualized) for
hhdclass"
        save 2hhdsutexp, replace

        use 2hhdsutexp, clear
        reshape wide sut_exp_adj, i(sut) j(hhdclass)
        renpfix sut_exp_adj hhd
        * apply labels for the SUT classes
        label define sut 1 "P1" 2 "P2" 3 "P3" 4 "P4" 5 "P5" 6 "P6" 7 "P7" 8 "P7gas"
9 "P7oil" 10 "P8" 11 "P9" 12 "P10" 13 "P11" 14 "P12" 15 "P13" 16 "P14" 17 "P15" 18
"P16" 19 "P17" 20 "P18" 21 "P19" 22 "P20" 23 "P21" 24 "P22" 25 "P23" 26 "P24" 27
"P25" 28 "P26" 29 "P27" 30 "P28" 31 "P29" 32 "P30" 33 "P31" 34 "P32" 35 "P33" 36
"P34" 37 "P35" 38 "P36" 39 "P37" 40 "P38" 41 "P39" 42 "P40" 43 "P41" 44 "P42" 45
"P43" 46 "P44" 47 "P45" 48 "P46" 49 "P47" 50 "P48" 51 "P49" 52 "P50" 53 "P51" 54
"P52" 55 "P53" 56 "P54" 57 "P55" 58 "P56" 59 "P57" 60 "P58" 61 "P59" 62 "P60" 63
"P61" 64 "P62" 65 "P63" 66 "P64" 67 "P65" 68 "P66" 69 "P67" 70 "P68" 71 "P69" 72
"P70" 73 "P71" 74 "P72" 75 "P73" 76 "P74" 77 "P75" 78 "P76" 79 "P77" 80 "P78" 81
"P79" 82 "P80" 83 "P81" 84 "P82" 85 "P83" 86 "P84" 87 "P85" 88 "P86" 89 "P87" 90
"P88" 91 "P89" 92 "P90" 93 "P91" 94 "P92" 95 "P93" 96 "P94" 97 "P95" 98 "P96" 99
"P97" 100 "P98" 101 "P99" 102 "P100" 103 "P101" 104 "P102" 105 "P103" 106 "P104"

        label values sut sut
```

```
        sort sut
        * save dataset
        save ..\Output\hhdexpSUTuse, replace
        * export to excel file
        export excel using "..\Output\\$year.xlsx", firstrow(varlabels)
sheetreplace sheet("2. SUT(exp)")
```